Cars for Cities

A study of trends in the design of vehicles with particular reference to their use in towns

Reports of the Steering Group and Working Group appointed by the Minister of Transport

London: Her Majesty's Stationery Office, 1967

Report of the Steering Group

The Steering Group

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To: The Right Honourable Barbara Castle, M.P., Minister of Transport

1. We were set up in June 1964, by the then Minister of Transport, the Right Honourable Ernest Marples, M.P.,

> 'To advise the Minister on future trends in the design of power-driven road vehicles, with particular reference to their use in towns.'

We were constituted as a Steering Group for this study, a separate Working Group being set up to undertake the more detailed studies needed. This soon became known as the 'Cars for Cities' study and we have adopted this title for our report, even though it is not a wholly apt description of the field defined by our terms of reference. In announcing the study in the House of Commons, the Minister said:

> 'In Traffic in Towns, Professor Buchanan drew attention to the tremendous impact of the motor vehicle on our way of life. I wish to announce two further developments.(1)
>
> First, the future of the motor vehicle. We all accept that it has come to stay but just as the towns of the future must be rebuilt to come to terms with the motor vehicle, so the motor vehicle must be designed to come to terms with those towns. For example, can't we design vehicles whose size, power and manoeuvrability make them more suitable for town use. And can't we reduce such things as noise and fumes. There are many aspects of design to be studied.'

We have been guided by this statement in interpreting our terms of reference. We have considered aspects of vehicle design that affect traffic congestion, parking space, air pollution, traffic noise, road safety and, simply, the intrusion of cars and vehicles generally. Our terms of reference related to all types of road vehicles but the predominance of cars among vehicles (in 1966 they constituted over two-thirds of all vehicles registered in this country), and the forecast rate of growth of car ownership (the forecasts show a rise for cars to over four-fifths of all vehicles by 1980) has led us to direct particular attention to them.

2. Our terms of reference were related to the vehicle but the study has shown that, as far as the size of vehicle is concerned, *very little benefit from reduced size can be realized without making changes in traffic conditions – in particular by segregating smaller cars from larger vehicles.* We discuss this in more detail later, but the significance of segregation can be seen from the Working Group's estimate that average sized cars, (2) if they could be given traffic routes to themselves, could move about a quarter as many people again in the road space they need when being driven in mixed traffic lanes 12 feet wide. In the same road space, present day very small cars(3) could increase capacity to a little over one and a half times while the 'optimum' vehicle that the Working Group have been able to envisage could increase it to just over twice the present level. On the other hand, the benefits from even the 'optimum' vehicle when it is used in mixed traffic are only 10–15%. In short, there is very little benefit, in terms of space needed while moving, from smaller cars unless there are accompanying changes in traffic conditions. It follows that to have restricted the study solely to the vehicle, without regard to traffic conditions – and in particular to parking facilities – would have precluded an assessment of the full range of benefits potentially available from developments in car design itself.

3. The Buchanan and Crowther Reports(4) analysed some of the problems created by traffic in towns. They brought out clearly the difficulty of adapting towns to the potential growth of car traffic, particularly if urban environment is to be improved. They showed also that solutions based solely on town planning and road building, necessary though these are, are fraught with great difficulties in this country. Our heritage of buildings worthy of preservation; the spider-web pattern of roads – as opposed to the grid-iron pattern often found in the USA; the lack of available land for the development of low-density, highly-motorised forms of urban community; all these added to the difficulties of finding solutions to the problems tackled in 'Traffic in Towns', and contributed to the immensity of the task of solving them.

4. We accordingly regard our study as complementary to the Buchanan and Crowther Reports. Accepting the analysis developed in those reports, we have gone on to consider what changes in the design of vehicles could contribute towards solving the problems of traffic.

5. We were not given a fixed time-scale against which to work, nor have we restricted ourselves to a single time-span. In, say, 30–40 years many developments involving either mechanical invention or major measures of urban renewal and re-planning – may have occurred. But less relief can be looked for from these sources in a shorter period. Moreover, present forecasts show that the rise in car ownership will become much less steep in the 1990s. It is, therefore, during the next 20 to 25 years that any relief will be particularly valuable. On the other hand, the nature of the motor vehicle research, design and production processes are such that many of the major design features of vehicles that will be produced over the next four or five years have already been settled. This means that consideration of developments that might contribute to the quick solution of our problems has to take account of design decisions that have already been taken by motor manufacturers, with export requirements particularly in mind.

6. We have conceived our task as a Steering Group as being – first, to provide the general direction for the detailed studies of the Working Group and to review them as they progressed, and, second, to make a general appraisal of the conclusions reached by the Working Group and to evaluate their broad implications.

(1) The Minister's second announcement dealt with a report on '*Road Pricing*. The Economic and Technical possibilities', HMSO, 1964.
(2) i.e. about 14 ft 0 in long and 5 ft 2 in wide, such as the Ford 'Cortina' or Hillman 'Minx'.
(3) i.e. about 10 ft long and 4 ft 6 in wide, such as the British Motor Corporation's 'Mini'.
(4) *Traffic in Towns*, HMSO, 1963.

For these findings we must accept responsibility. The detailed analysis done by the Working Group remains their work. Their report follows. We do not propose to summarise it but we think it may be desirable, before commenting on it generally, to set out, in relation to each chapter, what we consider to be the main conclusions.

7. In Chapter 1 of their report, the Working Group review the general social and town planning background to the problem. They reach the conclusion that, although the next 20 years may see far-reaching changes in working and social habits, there will remain in towns the need, as we know it today, for moving large numbers of people over an enormous variety of routes, with particularly large numbers involved in the daily tidal flow to and from work. A continuation of present policies will mean an increase rather than a decrease in traffic congestion, so that any contribution that the design of the vehicle can make to solving this problem will be worthwhile.

8. We agree with this conclusion. But *we consider it essential to point out that traffic congestion at present is greatly aggravated by the low level of expenditure on new roads in towns.* The Buchanan Report drew attention to the disparity between expenditure on buying and running vehicles and on building the roads needed for their use and emphasised that this was a problem that society must face. We not only endorse this view; we are convinced that the disparity must be reduced by greatly increased expenditure on roads even if this means spending less in other sections of the economy. It is a matter of common observation that the rate of urban highway building – and indeed highway building generally – in this country lags behind that of other advanced countries with acute traffic problems. As a consequence, we have the worst traffic conditions of any country in the World. *We think the Working Group right to conclude that planning and highway solutions alone cannot cope with all our traffic problems, but we believe that they are by far the most important factors in resolving our traffic congestion.*

9. In Chapter 2 of their Report, the Working Group discuss the importance of vehicle characteristics, such as dimensions and performance, in relation to conditions in towns. The analysis has been used to determine the desirable characteristics of specialised cars for use in towns and to assess the benefits to be got from such cars. We are glad to note the contribution that experimental work at the Road Research Laboratory has played in the analysis of, for example, the significance of vehicle width in traffic conditions. Nevertheless there must remain the risk that the behaviour of a wider cross-section of drivers under ordinary traffic conditions will be different from that observed under laboratory conditions, even when on a full-scale test track. We think that what has been done is entirely adequate to demonstrate, in the way that was needed for this study, the road space needs of cars of different sizes and hence the potential savings from very small cars. But *we think that further investigations should be made, with a wide range of different types of driver, to decide finally the minimum width of lane needed for small car traffic.*

10. Chapter 3 of the Working Group's report relates to what is perhaps the central theme of this study – the scope for greater use of personal transport in towns – and we discuss this fully later. At this stage, we look at Chapters 4 to 9 which deal with some of the more general problems of vehicles in towns.

11. The Working Group discuss taxis in Chapter 4. They point out that in many towns there is already considerable freedom for operators to use the sorts of vehicles that will suit their and their customers' needs. But in some cities, notably London, conditions are much more restrictive. Although the purpose built London-type taxi seems to the Working Group – and to us – to fulfil its role well, we are much less satisfied that London-type restrictions act in the best interest of the travelling public.

We believe that the taxi has an even more important role in the future in providing personal door-to-door transport in towns and we agree with the Working Group that there may well be scope for a wider range of taxis than are allowed in some places at present. It seems to us that a taxi capable of carrying two passengers and luggage would be adequate for most journeys. Similarly, we think there is a need for larger vehicles carrying perhaps 12 or more passengers, which would bridge the gap between the present four seat taxi and the high capacity town bus. Such vehicles could, for example, cater for journeys between hotels and air and rail termini, central car parks and shops and also trans-city journeys for commuters. *We are satisfied that the statutory framework should be altered to ensure that taxis can be developed which not only attract the car user and possibly reduce operating costs but are also able to take advantage of any special segregated road facilities which may be provided in cities.*

12. Chapter 5 of the Working Group's report relates to buses. The Working Group conclude that in future more specialized vehicles may be needed in place of the general-purpose bus of today. They suggest that a greater variety of bus designs may help operators to provide a more attractive service to the public. This may well be essential if the emphasis at present being put on the role of public transport in towns is to be realised, particularly since the public is increasingly becoming a car-owning public, accustomed to the standards of convenience and comfort that the private car can provide. These are high standards against which to compete and as yet we see little evidence, either here or abroad, to suggest that public transport operators are, in fact, generally able to provide a service likely to attract the car-owner, except when there are very great restraints on the use of cars. *We think it important to press on with anything that can be done – by experiment or otherwise – to find out what sort of buses or services are most attractive to the public.* We think practical experiments in this field are worth far more than theoretical discussion.

13. In Chapter 6, the Working Group draw attention to the fact that, although the commercial vehicle is an essential user of town roads, it is also a significant cause of traffic congestion, both when moving and when parked at the kerbside whilst loading and unloading. They emphasize the trend towards larger and more specialised vehicles, the need for better loading and unloading facilities, preferably off the street, and the probability that traffic conditions will bring radical changes in present patterns of operation. All this will lead not only to changes in vehicle design and performance but also to the need to concentrate loading and unloading at the times and in the places of least congestion. This emphasizes the need to provide more adequate facilities for this purpose so as to secure the more efficient use of goods vehicles. We believe, therefore, that more impetus will need to be given to the use of mechanical handling equipment, removable containers and the provision of off-street loading and unloading facilities, coupled perhaps with the development of common interchange points away from town centres and greater use of scheduled services on designated routes. The way in which the goods vehicle should be developed to meet the changing needs of the community will obviously require careful appraisal of all the factors involved. But we feel that the trend is likely to be towards larger but more specialised operating units and we support the trend towards higher power to weight ratios, better acceleration and improved braking for commercial vehicles. *Particular attention will also need to be given to the reduction of noise if collection and delivery of goods at night is to become more widespread.*

14. Chapters 7 and 8 of the Working Group's report relate to safety and to vehicle noise. There are two general points we wish to make. On safety, we should like to emphasize both the need for more research and the importance of very close links between the research workers – in both the public and private sectors – in

this field and the vehicle manufacturers. Over the last few years much closer relations have been established and *we cannot emphasize too strongly the need for effective and continuous collaboration on road safety.*

15. On noise, the Working Group took as a starting point the Wilson Committee's proposed limits. This was no doubt sensible. But the Wilson limits were arrived at after a 'jury' of observers bad given their view on the noise levels acceptable from various classes of vehicle. Such views must, inevitably, reflect to some extent present experience of vehicle noise and we think that, were it practicable to produce very much quieter vehicles, there might well be a public demand for much higher standards than those proposed by the Wilson Committee. It is clear from the Working Group's report that *there are big engineering difficulties in reducing noise from heavy goods vehicles. We think more research should be devoted to this.*

16. Chapter 9 of the Report relates to air pollution, on which a great deal of work is being done. Air pollution from motor vehicles has led to some public concern and we think, therefore, that it is just as important to set public opinion at ease where, in fact, no identifiable hazard to health exists, as it is to draw attention to any circumstances where there is a need for public action. The Working Group, on the basis of work by the Medical Research Council and the Warren Spring Laboratory of the Ministry of Technology, draw attention to the possible health hazard from carbon monoxide from petrol engines but also report that there is no conclusive evidence that black smoke from diesel engines is a hazard to health – however obnoxious it may be.

17. We think it important that the air pollution problem should be viewed over a sufficiently long period. This, in fact, increases the possible significance in this context of the motor vehicle. In most British cities at present, the industrial and domestic use of fuel is responsible for most of the air pollution. But clean air policies for cities, improved methods of burning fuel and the prospects of increasing proportions of our energy requirements being met from nuclear sources and natural gas are likely steadily to reduce pollution from industry and from dwelling houses. At the same time the vehicle, and particularly the car, population will be rising rapidly. The significance of pollution from vehicles as a proportion of total atmospheric pollution is clearly going to increase.

18. The Working Group have suggested possible standards for black smoke from diesel engines and an interim limit on carbon monoxide emissions from petrol engines. *It seems clear to us that statutory standards will be necessary to achieve the sort of reductions in pollution from motor vehicles that are now appropriate.* But circumstances will change and we think it essential that any standards should be kept under review. The possible changed significance in future of petrol vapour and oxides of nitrogen provides an example of the need for this. The requirements of the export trade mean that our manufacturers are already developing the means of meeting the air pollution standards being imposed in the United States of America. We see no immediate need to apply such stringent standards to meet the very different problems in this country. Nevertheless, there is no room for complacency and we are satisfied that there is evidence of a growing need for more effective controls which must, of course, be properly related to the needs of this country. *In the meantime we agree with the Working Group's suggestions that a limit should be placed on the amount of carbon monoxide emitted and that crankcase fumes should be returned to the inlet side of the engine, as this can achieve a useful reduction in hydrocarbon pollution at little cost.*

19. From Chapters 1 and 2 and 4 to 9 of the Working Group's report it is clear that there is some scope for improvement in many of the ways in which motor vehicles impinge on towns. But there is little doubt that the big problem is the enormous and rising number of private cars and that the most benefit would be gained by segregating them from other types of traffic. We now look at this in more detail.

20. Chapter 3 of the Working Group's report considers the scope for greater use of personal transport in towns. The Group have identified the design features they consider desirable in cars intended specifically for use in towns. They have also considered the sort of highway and parking facilities that would be needed to get the most benefit out of such cars. Various other proposals, such as travelators, are often put forward as solutions to the urban transport problem. Such schemes may have a contribution to make. But the motor car is an existing developed vehicle that is already established and has proved, without a shadow of doubt, that the service it can provide – door to door personal transport – is one which is highly valued. Consequently, there can be considerable confidence that any system providing door to door transport for a greater number of people, and based on the adoption and development of the private car, would meet a known and established need.

21. The Group have attempted to draw up outline specifications for four different types of car specially suitable for use in towns and intended to derive the maximum benefit from minimum size – a 4-seater (Citycar 4), a 2-seater with side-by-side seating (Citycar 2S), a 2-seater with staggered seating (Citycar 2), and a single-seater (Citycar 1). All have four wheels. The design considerations relating to these layouts are discussed in the Working Group report; here we wish merely to comment on the possible benefits from such cars and from special roadway systems for them.

22. Two factors can contribute to reducing both the road-space and parking space needs of cars – uniformity of size and reduction in size. Securing uniformity in size means, in practice, the segregation of cars from other vehicles, and of small cars from larger cars. The savings of road space are set out by the Working Group in figure 3:13 which shows the potential gains, separately and together, from segregation and from smaller dimensions. By separating cars from other traffic and tailoring lane widths to car sizes, average-sized saloons could move a quarter as many people again on any given area of road as they are able to move on the present standard 12ft lanes. Present day small saloons could increase capacity by a little over a half. Citycars 2, on lanes of appropriate width, could increase capacity to about twice the present level. The analysis also shows that the extra number of people that can be moved within a given road space, simply by using smaller cars, but leaving them to run in present mixed traffic lanes, are modest – not more than 15%. As the figures show, segregation alone can produce gains much bigger than this; and *segregation makes possible the achievement of the full potential gain from smaller cars.*

23. Cars spend much more time parked than moving. Figure 3:14 shows that the increase in the number of small cars that can be parked in a given space, compared with conventional cars, is very great. In mechanical garages, five Citycars 2 could be parked in the space now allowed for one conventional car, whilst even at the kerbside there would be room for twice as many Citycars 2 as conventional cars. *In considering overall benefits the savings in both road and parking space need to be taken into account.* The Working Group have attempted to do this in figure 3:15 which shows that the overall benefit from the use of small cars on segregated road and parking space would be an increase in capacity to a little over 1½ times present capacity if existing small cars were used, while the use of the Group's 'optimum' citycar could more than double the capacity of road and parking space.

24. All this leads us to stress the significance of segregating small cars from other traffic. As the Working Group point out, the segregation of small cars can be achieved in various ways and in varying degrees. For parking space, segregation may involve no more than laying out street spaces or designing off-street facilities

to accommodate a small car rather than all sizes of car. In moving traffic, segregation could begin by progressively setting aside for the exclusive use of small cars existing streets, or parts of streets, and could proceed to the construction of new roadways and special intersections. Obviously, various degrees of segregation are possible – they might well correspond to various stages of implementation of a segregated roadway and parking system. Thus, initially some parking space – on and off-street – might be set aside for citycars and some provision made for them on the street by providing, say, fly-overs and under-passes exclusively for citycar use at some congested intersections. Such facilities could, of course, be much smaller and lighter in construction than would otherwise be necessary. As citycars became more widely used, parts of streets could be allocated for their exclusive use; later whole streets could be made available for parts of the day, and it would also become increasingly worthwhile to construct considerable lengths of new roadway – as the Working Group suggest. Moreover, as they point out, the lighter loadings and smaller dimensions of citycars would make possible exclusive 'overways' that were cheaper, lighter and smaller than conventional elevated general-purpose roads. Thus, although a complete system of segregated routes might take decades to provide, it could be introduced in stages in a way that would enable it to be used, and benefits to be got from its use – during the whole of its development.

25. Any segregated space – whether from new roads or by setting aside space on an existing road – involves a prior decision about the maximum vehicle width to be adopted. It seems to us that this need be no greater than that of existing very small cars and there would, as the Working Group show, be advantages, in terms of traffic capacity and particularly in parking space savings, in having a smaller width. But there would be little sense in adopting a width only very slightly different from that of small cars being produced at the time the decision was taken and we think it important that the Government should consider the industrial implications, as well as the traffic and parking advantages, of any particular dimensional limitation for a segregated system. We must make it clear that the adoption of any standard dimensions significantly different from those represented by normal demands could place our motor manufacturers at a considerable disadvantage, particularly in the export markets.

26. The idea of segregated roadways is not as unorthodox as it may at first sound. For inter-urban traffic, the concept is already being applied in the provision and use of motorways, from which several types of traffic are excluded. This is done in order to achieve a more efficient and safer use of those roads. In towns, the large potential demand for individual transport points to the small car as the appropriate basis for segregation. The 'overway' system proposed is, therefore, an extension into towns of a principle that is already accepted in the inter-urban field. The general-purpose roads would be left correspondingly freer for buses, goods vehicles and other traffic.

27. *For any given space, the extra number of people that could be moved compared with what is achieved under the present vehicle and traffic patterns, by having an integrated design of car, roadway and parking space is very large – an increase to more than twice the present level. This is a big gain. Although there would be considerable difficulties in achieving it, the benefits are so great that we think it vital to make a real effort to do so. We are convinced that this overall approach is essential if big savings are to be achieved in the space needed by individual cars.*

28. Creating such an efficient system of personal road transport in towns may take some years. Planning and investment decisions, including decisions about the nature of town transport systems, must, therefore be taken long before the facilities are needed. This increases the need for early decisions.

29. Our final comment on the possible use of specialised citycars relates to the problem that is now recognised as central to urban transport policies – the respective roles of public and private transport. We know that enabling people to satisfy their desires to use cars extensively in towns creates enormous difficulties. But it seems to us that the pressures for people to do this may be equally large. There will always be a role for public transport, as we have recognised earlier. But we believe that in assessing the relative attractiveness of different proportions of public and private transport, weight should be given to making it possible for people to do what they want. We believe that an integrally designed system of vehicles, roadways and carparks could contribute significantly to achieving this objective. All this is foreseeable with present automobile and civil engineering techniques and the Working Group's report sets out the general concept. There are, of course, many problems to solve and we think it important that the practicability of various methods of segregating different types of traffic should be studied in greater depth. As a start, *we consider that full scale design and cost studies should be commissioned with a view to the early development of aesthetically acceptable special overhead road structures and networks and parking facilities for the exclusive use of small citycars.* We are convinced that this is a field in which practical experiments are worth a great deal more than theoretical discussion and that, in view of the likely scale of the savings in cost, a limited number of experimental schemes should be commissioned as soon as possible.

30. It is often suggested that conventional vehicles should be prevented from coming into town centres and that, for example, some form of pool hire system coupled perhaps with interchange car parks might provide an acceptable solution to the problem of traffic congestion. At first sight this seems an attractive idea but we agree with the Working Group's conclusion that there would be big difficulties in devising a satisfactory system of communal ownership or compulsory interchange, separately or together. We realise that unforeseen developments might change the situation but, as things stand, the disadvantages clearly outweigh the advantages.

31. We also consider it important to look at the longer term and what might be achieved with more research. Chapters 10 and 11 of the Working Group report relate to developments in the fields of power sources and automatic vehicle guidance. We have little to add on the details of what is said, but a general consideration applies to both these chapters. The Working Group take a cautious view of the time needed for new developments in power plants and electronic control, but the rate of development of a new device is directly related to the scale of effort applied to it. *We think that a co-ordinated research and development effort directed towards new forms of storage battery, fuel cells and advanced gas turbine engines and indeed any other prime moving device with low noise level and inobnoxious exhaust should be mounted on a much more ambitious scale than at present.*

32. It is, of course, essential to differentiate between practical endeavour and mere speculation but we realise that there is always the possibility of a major development in personal transport because of some discovery or invention which we cannot at present visualise. The rapid strides now being made with the miniaturization of a number of devices might, for example, lead eventually to the replacement of vehicles by machines which can be strapped to the person. Other possibilities are the development of some more compact form of personal transport based on the air cushion principle and the widespread introduction of multi-speed travelators. There may prove to be other novel means of transport resulting from the development of new materials, new techniques and more refined manufacturing processes. In the meantime we are satisfied that much better use can be made of existing means of road transport and in particular of the motor car.

33. We believe that the realisation of the ideas we have put for-

ward in this report will not be possible without either new administrative machinery or at least inspired use of the existing machinery. Under the threat and stimulus of war, Governments have been able to find ways of directing and financing the technological developments seen to be necessary for the survival of our nation. Outstanding examples have been the development of radar, atomic energy and the jet engine. The same sense of urgency seems never to have attended the developments necessary for the survival of our nation in times of peace. Today the problems of our existence in a highly competitive and not particularly sympathetic world are as testing as the problems with which we were faced in war. One of the most vital which has to be solved is the problem of physical communications in the United Kingdom itself. We realise that our terms of reference do not extend as far as these remarks would by themselves imply but we find it difficult to conceive that the attempted solution of the problems of urban traffic will not lead ultimately to the consideration of communication systems for the country as a whole.

34. All this suggests to us that means for the close co-ordination and the rational financing of the highway work of local authorities should be found. It also suggests to us that the power plant developments we have adumbrated, the overways we have sketched, the traffic planning we have recommended need to be prosecuted with a sense of urgency on a scale of financing not hitherto applied in these directions. It seems to us that there is a great opportunity for the Ministry of Technology and the Department of Education and Science to join with the Ministry of Transport in the developments which we have outlined.

35. That the talent exists to solve the problems we have no doubt and we think that some of our national and university laboratories, which sometimes feel a lack of realism in their objectives, could, for instance, be led to put far greater weight than they do at present on some of the longer term power plant, structural engineering and traffic engineering problems. The aftermath of the Crowther/Buchanan Report has been a developing interest in planning towns for the traffic they will have to accommodate. We would like to see this extended not only to an interest in the kind of vehicle and traffic problems we have been discussing but to early practical experiment.

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October 1966.

Report of the Working Group

The Working Group

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Report of the Working Group

The Rt. Hon. Ernest Marples announced on the 14th September 1964 our appointment as the Working Group for this study. Our terms of reference were the same as those of the Steering Group, i.e.,—

'To advise the Minister on future trends in the design of power-driven road vehicles, with particular reference to their use in towns.'

These exclude fixed track systems – railways, monorails, travelators and so on but we have included within our study the possibility of some form of automatic guidance of vehicles for part of their journeys.

The Steering Group have helped and guided us throughout the study. At the beginning they asked us to consider developments that might be possible during the next twenty-five years and to include in our study factors that could affect traffic congestion, road safety, noise and air pollution There are already over twice as many cars as all other sorts of vehicle and the proportion of cars will rise further over the next twenty years. We have reflected this in the weight we have given to considering the car.

We have received unfailing help and courtesy from all the organisations and individuals whom we had occasion to consult. Many organisations and private individuals have put before us ideas and proposals and have sometimes demonstrated to us vehicles or prototypes that they had themselves developed. We are grateful for all these ideas and for the help we have received from organisations and individuals. The organisations with which we have been in touch are listed in Appendix 'A'. Throughout our work we have been most helpfully served by our Secretary, Mr J. W. Furness, who has not only coped most efficiently and courteously with the ordinary range of duties that fall to a secretary, but has also been of the greatest help through putting at our disposal his technical knowledge and experience. We are also very indebted to Mr K Peter and, during the latter stages of the study, to Mr P. Radley. Miss S. M. Hier and Miss E. C. Evans have ensured the smooth working of the administrative arrangements We are most grateful to them all.

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R A Fryars
C A. Griffin
G. Grime
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C. G. Williams
E. Woodbridge

J. W. Furness (*Secretary*)

September 1966

1 Vehicles in towns

To set our study in perspective, we have looked first of all at the physical and social framework within which the motor vehicle has developed and have considered the ways in which social change, town-planning or road-building may affect the nature or scale of the problem.

Vehicles are for moving people and goods with the minimum human effort. They have always been associated with town life and the problems linked with their use – congestion, noise, air pollution and the risk of accidents are all intensified, if not created, by the high density of vehicles in towns. But these problems are not new. Outcries against the evils of road traffic in London have been made at least since Stuart times; the Report of the 1905 Royal Commission on London Traffic(1) shows how long some current problems have been with us. What is new, however, is the scale of these problems. Firms and individuals can own their own transport on a scale never before possible. The combination of concentrated town dwelling, growing economic activity and the motor vehicle has created a situation in which a restricted urban road network is becoming impossibly overburdened with traffic it was never designed to carry. But congestion is not the only penalty we pay for our use of the car. It has encouraged urban sprawl and in some places the effects of the motor car on the urban environment have been disastrous.(2) So we have the paradox that an intrinsically desirable and useful method of transport has created as many problems as it has solved.

The use of road vehicles affects the individual user and the rest of the community in different ways. We see no reason why the ordinary processes of the market should not lead to vehicles being developed in the way that the individual user broadly wants. The effect of motor vehicles on the public at large is another matter. Noise, accidents, atmospheric pollution and the sheer road space taken up by a vehicle are all impositions on the community as a whole, but as they are not directly reflected in the price the individual user pays when buying or running a vehicle, the individual's choice of vehicle is unlikely to take account of the public interest. This situation can create a conflict of interest between the individual user and the public. It is particularly where this sort of conflict may arise that we have examined in some depth the characteristics of vehicles. In doing so we have looked at the interests of the community as a whole. We have, in effect, been considering what aspects of vehicle design it would be desirable to influence, so as to make possible the maximum use of road vehicles – and particularly cars – with a minimum loss of amenity.

1.1 Town growth

An ever-increasing proportion of the population lives in towns. At present, about 80% of the inhabitants of England and Wales are concentrated in one-tenth of the total land area. It is forecast that by the end of the century some 90% of a much larger population will live in towns.(3) The big conurbations are spreading into the surrounding countryside and their 'commuter belts' are steadily being extended. One indication of this is the greatly

(1) Cmnd. 2597 (1905).
(2) See *Traffic in Towns*, HMSO, 1963.
(3) Quarterly Return of the Registrar General for England and Wales, December 1965.

Plate 1-1 Traffic congestion – old style, London Bridge 1892

Plate 1–2 Traffic congestion – new style, Putney Bridge

above-average population growth rate of the small towns and villages in the counties around London and Birmingham (see figure 1:1).

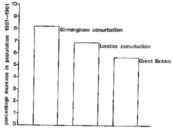


Figure 1:1 Growth of London and Birmingham conurbations 1951–1961

There are two major features of the pattern of population concentration in this country that have implications for traffic and which seem likely to continue over the next 25 years. The first is the drift of population to the Midlands and to the South,[4] the second is the growth of suburbs around our major cities generally, with relatively fewer people living in city centres (see figures 1:2 and 1:3). There is also a trend towards a faster growth of shop, office and factory development in the suburbs than in the centres of towns.[5] These trends mean that traditional notions of where the individual 'town' ends and 'country' begins are becoming increasingly unrealistic.

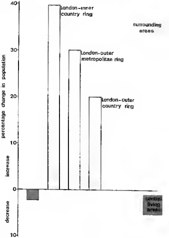


Figure 1:2 Changing spread of population in London 1951–1961

(4) See, for example, *The South East Study* 1961–1981, HMSO, 1964, and *The West Midlands*, HMSO, 1965.

(5) See, for example, *London Traffic Survey* (1962), vol. 1, L.C.C. 1964.

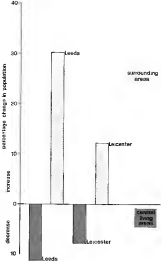


Figure 1:3 Changing spread of population in Leicester and Leeds 1951–1961

1.2 Car ownership and use

A dramatic increase in vehicle ownership in the United Kingdom over the next half century, and in particular in the ownership of cars can be expected (see figure 1 4), with the car forming an increasing proportion of the total vehicle population. Forecasters expect the maximum level of car ownership per head to be reached early in the 21st century. This recognises that there will always be some people who cannot or do not wish to own cars –

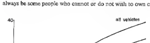


Figure 1:4 Forecast of the growth of car and vehicle ownership

such as the disabled, the infirm, the very old and the very young and voluntary non-drivers – and there is a limit to the number of cars which it is useful for a person to own. Density of population also influences the level of vehicle ownership: after a certain point ownership levels fall off with increasing density of population. Figure 1:5 shows estimates of the saturation level for different types of area.[6]

Detailed forecasts of car ownership are inevitably uncertain. But the general trend is unmistakable. Even now, in most towns, the demands for road and garage space already overtax existing facilities. Everything points to a very great increase in ownership; and ownership creates a corresponding potential demand for use.

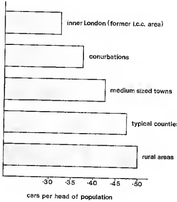


Figure 1:5 The saturation level of car ownership for different types of area

Population range	Average Speed (mph)
250,000 – 500,000	14
110,000 – 170,000	13
67,000 – 81,000	13
36,000 – 43,000	16
18,000 – 20,000	16
9,000 – 10,000	16

Figure 1:6 Average speeds in the central areas of towns of varying size (off-peak periods)

[6] Derived from forecasts by Mr J. C. Tanner of the Road Research Laboratory.

Traffic congestion in towns tends at present to be concentrated at peak hours and on particular routes, largely because of the concentration of places of employment coupled with relatively standardised times of starting and finishing work. There is a large radial flow, with people travelling to town centres from the outskirts in the morning and going home in the evening. In some smaller towns there is also a mid-day peak. Traffic speeds fall, the closer one approaches the centre of a town. Figures 1:6, 1:7, 1:8a and 1:8b illustrate some features of town traffic. They suggest the speed of traffic in the centres of towns of very dissimilar size and character varies only slightly. In terms of peak hour traffic speed, congestion is almost as acute in small towns as it is in big cities. But there are important differences. Peak congestion usually lasts for a shorter time in small towns and it seems likely that a slightly greater flexibility in hours of starting and finishing work in large cities, coupled with more geographical spread of jobs, enables the commuter traffic to spread itself out more widely around the peak. In small towns, a much higher proportion of commuters travel by private car than in large cities. In the latter, the major part of peak hour travel is by public transport.

Road Research Laboratory studies in 48 towns have shown that in smaller towns the volume of peak traffic is proportional to population, but that larger towns do not have a similarly proportional volume of peak traffic. At the same time the increase in peak-hour flows in recent years has been much less in large cities than in smaller towns. The explanation is probably that in the former traffic flows at peak hours are already at or near capacity so that any increase in traffic must come at other times of day. In such circumstances whenever traffic engineers increase street capacity additional vehicles quickly appear to absorb most of the increase.

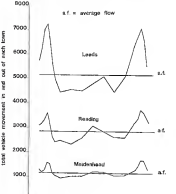


Figure 1:7 Traffic flow in and out of towns

We conclude from all this that the high usage of public transport in large cities is brought about to some extent by the difficulties of using cars in them. There is, in effect, an unsatisfied demand for car use which will increase as car ownership increases. This may be offset a little by the increasing distance that people are prepared to travel to work and the comparative attractiveness of

rail travel for longer-distance commuting. But this would not affect the general picture very much.

1.3 Possible social developments

Hours and conditions of work are likely to change. It is sometimes suggested that automation will eventually eliminate commuter congestion, in that the continued substitution of machines for human labour may so reduce the number of days per week and hours per day of work for the average person that the need for congested peak hour travel will disappear.

At the moment however it is impossible to fit a time-scale to such prospects. There has been little recent reduction of actual hours worked (see figure 1 9) Some commentators[7] have suggested that a further reduction of ten hours in the actual working week for manual workers might be expected by the mid-1980's. Even so, the peak hour problem would remain unless a much wider variety of starting and finishing hours were established than at present exists So far, reductions in hours worked by some groups have tended to aggravate the peak problem, by shortening the time over which the peak is spread. Even if future technological

Figure 1:8a Percentage of persons entering central areas by road in period 7–10 a.m. travelling by various forms of transport

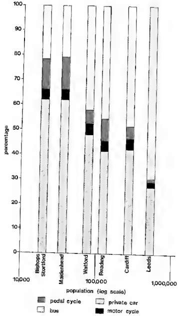
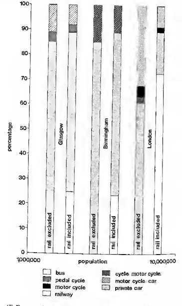


Figure 1:8b Percentage of persons entering central areas in period 7–10 a.m. travelling by various forms of transport



[7] For example, R. M. Newland *The Peak Hour Problem* in *Roads and Road Construction*, vol 42, No. 494, February 1964.

Figure 1:9 Changes in actual weekly hours of work for men 1950–1965 (The hours recorded are those actually worked by manual wage earners)

Plate 1–3 'The increasing use of cars for recreational and holiday transport already causes serious congestion on routes to popular areas'

and social developments should make the present scale of commuter travel unnecessary, we cannot assume that people will not still want to meet personally on both a large and a small scale On the contrary, wider car ownership generates more travel, particularly for social purposes, and this may create new problems (see figure 1:10). The increasing use of cars for recreational and holiday transport already causes serious congestion on routes to popular areas and in some resorts, while city congestion is beginning to arise from recreational as well as work journeys On the other hand, greater flexibility in recreational travel patterns may be expected as leisure and incomes increase.

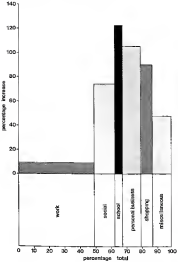


Figure 1:10 Estimated increase in vehicle journeys for various purposes in London 1962–1981

1.4 Possible planning developments

New planning principles and techniques can help reduce the undesirable aspects of the impact of the car on the town. The concept of functional segregation lies behind most plans for urban renewal, different areas within a town being set aside for particular uses. The Buchanan Report[1] adopted this approach and recommended that main traffic flows ought to be channelled on to 'primary route networks' and that 'environmental areas' should be established where traffic needs could be subordinated to the quality of the environment. New town forms can do much to help cope with the motor vehicle (see, for example, figure 1:11). The 'linear city', the 'star-town'[2] concept, and simply the dispersal of traffic generating activities are all suggested methods of fitting the town and vehicle better together. But such proposals are essentially for new towns and can contribute little to solving the problems of existing towns.

In the main we accept the analysis of the detrimental effect of the car on town conditions. But we have certain reservations about the nature of aesthetic judgments and the practicability – and even desirability – of 'community'. Aesthetic judgments are subjective and variable. Cars and roads are not in themselves ugly to everyone, and not everyone's ideal of beauty involves greenery and quiet. Some people find it exciting as well as convenient to live in a busy city, with traffic contributing to its hustle and bustle. We appreciate the desire of those who seek quiet, residential areas characterised by cul-de-sacs, parks and squares; but such surroundings do not represent an absolute standard of urban amenity. Tastes can differ.

[1] *Traffic in Towns*, HMSO, 1963
[2] See glossary

Plate 1-4 What full motorisation means for a town of modest size

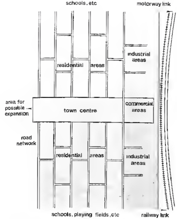


Figure 1:11 Illustration of the layout of a linear city

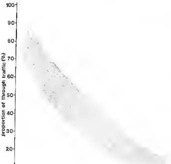


Figure 1:12 Relationship between town size and the proportion of by-passable traffic on the approach roads

(10) See Ministry of Transport *Highway Statistics* 1964, HMSO 1965.
(11) See for example R. J. Smeed – *The Traffic problems in towns A review of possible long-term solutions*. The Town Planning Review, 1964, Vol XXXV(2).

Judgments about the best form of social structure often go hand-in-hand with the aesthetic judgments to which we have just referred. Behind many new town concepts lies the notion that city dwellers have no sense of belonging and that it is necessary to create a sense of 'community'. We would contend that the argument may be overstated, firstly, because it exaggerates the degree to which cities in fact break up communal ties; and, secondly, it assumes the desirability of rooting our social structure in a simple, geographical unit. Modern communications and transport make possible a wider choice of social activities than in the past. Ours is a complex and, above all, an increasingly mobile society, and we would suggest that it may be a mistake to assume that many people want to live in small self-sufficient communities. Close communities can be constricting as easily as they can be satisfying.

1.5 Possible highway developments

It is often assumed that better roads in towns might solve the problem of traffic congestion. There are two sorts of road development that affect urban traffic – new roads that take through traffic out of towns altogether; and those that help to cope with traffic having business within a town itself. Obviously, some roads do both.

By-passes reduce through traffic in towns. But the relief they can offer to town traffic is limited. Although the traffic that uses a by-pass may seem considerable, it is often, as figure 1·12 shows, only a very small proportion of the total traffic within a town. It is only in very small towns that the through traffic forms a significant part of total traffic.

In some cities traffic congestion may already deter some people from using cars. The freer-flowing conditions that result from removing some through traffic will then lead to more local traffic. And above all, there is the steady long-term growth of internal and terminating traffic – about 7% a year in most towns.[10] All this suggests that by-passes are unlikely to give permanent relief to urban congestion. The crux of the urban road problem lies in finding ways of dealing with the growing volume of internal and terminating traffic generated by towns themselves.

As to new roads within towns, we do not think it is necessary to set out here the arguments pointing to the improbability of roads in towns being provided in this country on such a scale as to solve all traffic problems. This is not to under-estimate the need for new roads in towns, nor the possible benefits to be got from using road patterns that tend to reduce congestion.[11] But like Buchanan, we see no prospect of a complete solution to town traffic problems from new roads.

1.6 Realistic prospects

Many of the more imaginative planning ideas could no doubt greatly alleviate traffic problems but the more dramatic solutions cannot be extensively implemented in the time scale of this study. New travel patterns based on very short working hours, new town forms that would reduce the need for personal car travel or highway patterns that would avoid congestion, seem to us to be only very long-term possibilities. The current planning proposals in many cities retain a concentrated central area and a radial road pattern of limited capacity. It therefore seems to us inevitable that many of the traffic problems of the present – including the peak hour problem as we now know it – will remain with us for at least the time-period with which this study is concerned, and perhaps for much longer. A different kind of personal transport could perhaps help to solve this problem. We have seen the detailed examination of the scope for such a development, and of the means by which most benefit might be got from it, as one of the more important functions of our study.

2 Vehicle size and performance

In Chapter 1 we concluded that whatever changes there may be in social habits, in urban layout and in the scale of road building, these alone will not solve, within the time-scale we are considering, the problems created in towns by the motor vehicle. In this Chapter we have attempted to assess, and to quantify wherever possible, the importance of vehicle size and performance in relation to urban traffic and parking needs. In later chapters we discuss possible changes in vehicle design and consider the benefits that these changes might offer.

The vehicle characteristics we now consider are

(a) size — length, width and height;

(b) performance — speed, acceleration, hill-climbing ability and braking;

(c) manoeuvrability, including turning circle and driver's visibility;

(d) handling qualities and general ease of control.

For some factors, the absolute performance of a vehicle may be important; for others, securing uniformity among vehicles, rather than any absolute standard may be important; for some factors it may be both.

2.1 The significance of size in traffic

We have attempted to assess the significance of vehicle size by making a theoretical analysis of the total road space taken up by each vehicle in a traffic stream, and relating this, as far as possible, to experimental work. In so doing, we have recognised that the capacity of urban roads depends on many factors, some of which could not readily be analysed and would be difficult to reproduce under test conditions.

A car moving along a road can be thought of as being surrounded by an imaginary 'traffic envelope', related to the length and width of the vehicle, the speed at which it is moving, and the road width available to it. Using this approach it is possible to obtain an indication of the gain in traffic capacity that might result from the use of very small vehicles. In this admittedly simplified concept, the length of the envelope is made up of the length of the vehicle itself plus the distance between it and the vehicle in front, and the width of the envelope is that of the vehicle plus the necessary sideways clearance. Where a vehicle is travelling in a single lane between two kerbs the clearance needed can be considered to be the difference between the vehicle width and the width between the kerbs; where a vehicle is travelling in a lane between other lanes of vehicles, it can be considered to be half the total space between a vehicle and the vehicles on both sides of it. Thus in uniformly spaced traffic, the clearance is equal to the sideway space between two vehicles in adjacent lanes. The height of the envelope does not affect the amount of road space needed, but it may affect the design of the road system as a whole.

Plate 2-1 Road space taken up by present day cars as an imposition on the community

2.1.1 Length

The traffic envelope for a stationary vehicle is not much longer than the vehicle itself. The total length of the envelope, or 'headway',(1) becomes progressively greater as speed increases, and the length of the vehicle itself becomes progressively less important. Figure 2.1, which is based on work by Professor

(1) Headway can be represented by the formula

$$H = L + K_1V + K_2V^2$$

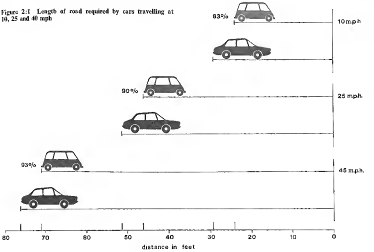
where H is the headway in feet, L is related to vehicle length, V is the speed in mph, K_1 is related to the reaction and response time of the driver and of the vehicle braking system, and K_2 is related to the difference in retardation between the vehicle and the one next in front of it. Professor R. J. Smeed has suggested the following values for these constants:

$$L = 17{\cdot}5 \quad K_1 = 1{\cdot}17 \quad K_2 = 0{\cdot}0079$$

They are based on observations and experiments made in 1947, and relate to vehicles moving in single file. The values adduced may therefore need qualification; but the principles remain unchanged. In making comparisons of the headways needed for various sizes of car we have used Professor Smeed's values for K_1 and K_2, but we have had to make an assumption about the relationship between L and actual vehicle length. British cars are, on average, about 14 ft long. We have therefore used a factor of $1{\cdot}2L_1$ instead of L, where L_1 represents actual car length in feet.

Smeed, illustrates this; in single file at 25 mph, cars 10ft long take up nine-tenths of the headway needed for cars 14 ft long So, in moving traffic, the benefit from having short vehicles is small, in terms of gain in traffic capacity.

Figure 2:1 Length of road required by cars travelling at 10, 25 and 40 mph



2.1.2 Width

Vehicles that run on fixed tracks, such as trams, need little more than their own width of roadway. But they are a special case. The driver of an ordinary road vehicle needs room to steer a course, with some margin for safety. We found that very little was known about the relationship between vehicle width and the minimum width of road needed. We therefore asked the Road Research Laboratory to do some experimental work on this, with large and small cars on various road widths at speeds between 15 and 50 mph. These experiments were made on tracks without lane markings, and it seemed that under these conditions the capacity of all but the narrowest roads increases proportionally to their width. Further experiments would need to be done to find out the effect of marking the road out in lanes, but it seems likely that with generous lane widths there would be less efficient use of road space, though safety and driving comfort might be increased. On the other hand, very narrow lanes are likely to be detrimental to safety and comfort. The behaviour of drivers of an existing type of small car used in the Road Research Laboratory's experiments suggests that, at town traffic speeds, a lane width about 2 ft 6 in to 3 ft greater than the car itself represents a reasonable minimum.

In mixed traffic on roads in marked lanes there is a tendency for small vehicles to travel in the shadow of larger ones. It seems sensible to expect a greater traffic capacity when traffic is made up of vehicles of similar size, and greater safety and driving comfort might also result.

The traffic envelope concept cannot be applied to the situation at traffic lights, which are the usual bottle-necks in towns. However, the Road Research Laboratory have made experiments, using small cars about 4 ft 6 in wide and 10 ft long, to see what effect vehicle size has on the flow of traffic at light-controlled cross roads. Tests were made with these cars by themselves and mixed with other traffic that ranged from medium-sized cars to heavy lorries. They showed that when traffic was made up of these small cars alone, the road space they occupied was only about two-thirds of that needed for an average car in mixed traffic. In mixed traffic, however, the small cars needed nine-tenths of the space required by an average car.

2.1.3 Conclusions on road space needs of vehicles in traffic

Length alone is not very important in determining the amount of road space a vehicle needs when on the move and its importance diminishes as speed increases. At town traffic speeds, width is

Plate 2-2 Road Research Laboratory experiments in progress

much more important. In mixed traffic on roads marked in lanes suitable for the larger vehicles present, it is likely that some of the advantage of having narrow vehicles is lost. This suggests that the best use of road space would be made by narrow vehicles of uniform width running in lanes tailored to fit them.

2.2 The significance of size in parking

Generally, vehicles spend more time parked than moving. Already there is not enough garage room for the car population, either at their 'homes' or at their destinations. Even allowing for the possibilities of parking underground, car parks are already becoming prominent features of the townscape. The cost to the user may become a significant part of total car running costs. So the effect of vehicle design on parking space needs is very important.

Plate 2–3 'Already there is not enough garage room'

Car design is always changing. Long-term trends are unpredictable although successive models of family saloon cars have tended to become wider, longer and lower over the past 20 years. Garages, car parks and street parking bays are normally designed to accommodate the largest and least manoeuvrable cars likely to use them, and to allow for some growth in size.[2] Car parks could possibly be laid out in such a way that cars could be segregated by size, with long and short cars parked end-to-end in pairs, or with areas set aside for very small or unusually large cars. This would complicate parking but would be theoretically worthwhile if the savings in space per car were large enough. Whether it could be made to work in practice could be tested by experiment.

We have considered how vehicle design can contribute towards saving parking space and towards making the parking manoeuvre safer, easier and less obstructive. The space needed for parking a vehicle is determined mainly by the diameter of the circle swept by the outer front corner and the path followed by the inside rear wheel; but overall length and width, track, wheel-base, body overhang (front, rear and side), kerb clearance and door location and width are also significant. The amount of space needed for manoeuvring a car into a parking bay also depends on the angle at, and the way in which cars are parked and the design of the park itself. In drive-in covered car parks, sufficient headroom has to be allowed for drivers and passengers to get to their cars; car height is therefore not significant except in mechanical parks.

2.2.1 Street parking

In ordinary streets, the most space-saving parking layout for present-day cars is in paired bays[3] parallel to the kerb. Angled parking and parking nose or tail to the kerb are only practicable in wide streets with little traffic. Street parking might be easier if cars could be moved bodily sideways, or could pivot about one end. This would not necessarily make parking safer or less obstructive, but if all cars were to be so designed perhaps 10–15% more cars could be parked against the kerb by this means. Safety and obstruction considerations apart, we doubt very much whether this saving in parking space would justify the cost of equipping cars to manoeuvre in this way.

With random kerb-side parking, and in paired parking bays the kerb length taken up is about 18 feet per car. Three small cars 10 ft long and 4 ft 6 in wide could be parked in the kerb length normally taken up by two average-sized cars. Because of their narrowness these small cars would also leave more road width for moving traffic. Smaller cars, less than 7 ft 6 in long, could be parked end-on to the kerb on ordinary streets, and five could be got into the parking space now allotted for two ordinary cars. But whether it would be better to use road space in this way or to have side-on parking and leave more room for moving traffic would depend on local circumstances.

2.2.2 Off-street parking

It is becoming generally recognised that roads are for moving traffic and for access to premises. In future, car parking will increasingly be off-street. The demand for land in the centres of cities is so strong, and surface parking is so wasteful of ground space, that the trend is towards multi-storey parking, above or below ground. There are many different layouts, but most include access aisles with bays at right-angles to them. The depth of the parking bay depends on the clearance needed at each end of the car. If cars were of fairly uniform length and front overhang, the front wheels could be run up against chocks and only very small end clearances would be needed. The width of the bay is, in

Plate 2–4A 'Parking will be increasingly off-street'

[2] For example, the Ministry of Housing and Local Government recommend a garage 16 ft by 8 ft for a car of standard design.

See *Cars in Housing* HMSO, 1966.

[3] Paired bays are those in which a single length of manoeuvring space for getting in and out of the bay is common to two parking bays. Each bay is 16 ft long and 7 ft 6 in wide, with 4 ft between each pair of bays.

Plate 2–4a 'Parking will be increasingly off-street'

Plate 2–5 The obvious parking advantages of the very small car

practice, dictated by the car width plus the door clearance needed to let the driver get in and out. For comfort and to avoid the risk of damage, not much less than 2 ft is needed between vehicles, and this could not be significantly reduced by having sliding or upward swinging doors. Cars with the doors at the front or back would enable sideways clearance to be reduced by about a foot, but end clearance might then have to be increased. If very small cars could be stood on end, better use would be made of the headroom in drive-in parks, but space would still be needed off the aisle for access to the vehicle and for raising and lowering it, so that little or no advantage would result, except possibly in mechanical car parks. We do not consider this limited advantage would offset the inconvenience of not being able to leave loose articles in the car, quite apart from the design difficulties that standing on end creates.

2.2.3 Conclusions on parking

Unorthodox car designs do not seem likely to contribute very much to saving parking space, even assuming that most car users were prepared to accept them. Reducing size is another matter. If, for instance, all cars using a normal type of drive-in multi-storey garage were 10 ft long and 4 ft 6 in wide, the vehicle capacity of a park of given size could be increased by about two-thirds as compared with present standards. In mechanical parks, where reduction in vehicle height can be translated into savings in total volume occupied, a car of this size and 4 ft 6 in high, could increase the capacity of a site to two and a half times that achieved with present standards. Thus the advantages of small uniform-sized cars would be very considerable in parking as well as in moving traffic, provided that there were enough of them to justify having parking space specially for them.

The parking benefits, both on an off street, that might be got from very small cars are considered in more detail in the next Chapter.

2.3 The significance of vehicle performance

2.3.1 Speed

There are two possible sorts of benefit from higher speeds – gains in traffic capacity of a road and saving of time to the individual. High top speed (as opposed to the acceleration often associated with it) is obviously of most significance when vehicles travel at high average speeds. Town roads carrying mixed traffic normally have a speed limit of 30 mph or 40 mph, and there is usually a maximum speed limit of no more than 50 mph on urban motorways. Vehicles designed mainly for town use would not therefore need high maximum speeds.

The traffic capacity of a road depends on traffic speed and headways. Figure 2.2 shows relationships between traffic flow and traffic speed which suggest that under free-flowing conditions maximum capacity occurs at traffic speeds of between 25 and 40 mph, and in terms of traffic capacity there is little or no advantage to be obtained from higher speeds. But higher speed

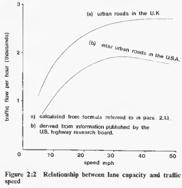


Figure 2:2 Relationship between lane capacity and traffic speed

saves travelling time, as figure 2:3 shows We therefore consider that cars used in towns should be able to maintain a speed of at least 40 mph on level roads. Performance requirements for buses and goods vehicles are discussed in more detail in Chapters 5 and 6, respectively.

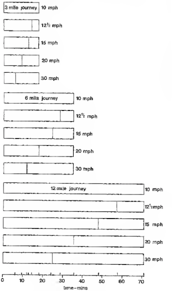


Figure 2:3 Savings in journey time (tinted area)

2.3.2 Acceleration

The significance of acceleration is less easy to establish. Drivers of powerful cars rarely use all the acceleration available to them, although some Road Research Laboratory experiments suggest that the greater the acceleration available, the more is used. In the stopping and starting progress of town traffic good acceleration from rest to cruising speed seems important. Figure 2:4 is based on a simple calculation of the number of vehicles that would theoretically pass through a traffic light controlled junction during a fixed period, assuming that all the vehicles started from rest and used the same acceleration. It appears from this that progressively less benefit is likely to be obtained from accelerations of better than about 3 to 4 mph/second, particularly with the longer 'green' times that tend to apply in congested urban traffic conditions.

The Road Research Laboratory have carried out practical tests of the effect on capacity, of using two groups of otherwise similar cars but capable of accelerations of about 3·5 and 5 mph/second respectively The higher acceleration increased capacity by about 5 to 10%. Mixing the higher and lower powered vehicles together resulted in a traffic capacity little different from that obtained when all the cars were lower powered. This suggests that the traffic capacity of a road may be influenced more by the acceleration of the worst-performing vehicles than by the potential acceleration of the better-performing vehicles.

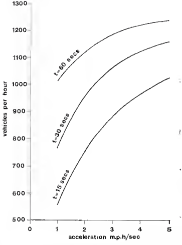


Figure 2:4 Simplified theoretical effect of acceleration at a traffic light controlled junction (t = green light time)

Figure 2:5 shows the theoretical effect of acceleration on journey times under stop/start conditions. The time savings from increased acceleration are naturally greatest when there are frequent stops. In typical urban traffic conditions four stops per mile are quite usual. Under these conditions, if acceleration were increased from 1 to 2 mph/second, journey time over five miles could theoretically be reduced by one-eighth. An increase to 4 mph/second could reduce it by a quarter. Better acceleration than this would not bring proportionate gains

We consider that an ability to accelerate at 4 mph/second up to 40 mph (that is to say, 0 to 40 mph in 10 seconds) would be an adequate performance for vehicles in towns, both in terms of road capacity and from the point of view of saving the user's travelling time.

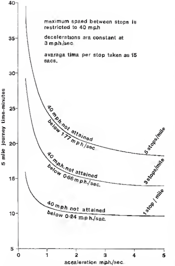


Figure 2:5 Simplified theoretical effect of acceleration on journey times under stop/start conditions

Plate 2–6 A vehicle with poor hill-climbing ability impedes other traffic

2.3.3 Performance up gradients

As explained in section 2.3.1, road capacity under free-flowing conditions falls off as traffic speeds drop below 25 mph. It is a commonplace that poor hill-climbers impede the flow of traffic. They can also greatly reduce the traffic capacity of a road. Present-day cars can climb the gradients found in most British cities at the sort of speed needed to make good use of road capacity. But buses and lorries are not always able to do so; and the power and weight characteristics of present battery-driven vehicles normally limit their hill climbing performance considerably. A gradient of 4% (1 in 25) is ordinarily regarded as the maximum acceptable on urban motorways and other main traffic routes. It would therefore be desirable for all vehicles to be able to maintain at least 25 mph up such a gradient when fully laden. But, as is explained in the next chapter, there could be circumstances under which a specialised car for use in towns would need a better performance than this, and would need to be able to maintain at least 25 mph up gradients twice as steep.

2.3.4 Braking capacity

Good braking can enable headways to be safely reduced and so can improve road capacity. On dry roads the braking of most present-day cars approaches the maximum practical efficiency, and most buses are easily capable of slowing down as rapidly as passenger comfort and safety allow. With the possible exception of certain types of goods vehicles and some two-wheeled vehicles, present braking capacities meet the foreseeable requirements for town conditions. The possibilities for improving braking performance as an aid to safety are discussed in Chapter 7.

2.4 Driver visibility, controls and stability

There are other characteristics that affect the suitability of vehicles for town use. Small turning and swept circles reduce the amount of space needed for parking. Good all-round visibility can also make a vehicle more manoeuvrable, though there are indications from experiments that the limitations imposed by poor visibility are largely overcome when a driver becomes thoroughly familiar with the vehicle. If all vehicles had automatic transmissions, the capacity of light-controlled intersections might be increased by 5 to 10%, according to tests by the Road Research Laboratory.

Stability and handling are also important but are difficult to express numerically. Good handling depends on many factors, such as the height of the centre of gravity, weight distribution, wheel-track, wheelbase, steering geometry,[4] and suspension characteristics. All these are important in the design of any road vehicle. The stability of most modern cars is very good and we do not think that any great improvement is needed to make them better suited to town conditions, even though the directional stability[5] of some present day vehicles on exposed open roads is not entirely satisfactory.

[4] See glossary.
[5] See glossary.

3 Personal transport in towns

Having considered the ways in which the dimensions and performance of vehicles affect the space they take up, both when moving and when parked, we considered the scope for the changes in personal transport that are desirable for town use. Changes in the ways in which personal transport is owned and used could greatly affect design and engineering. For example, some sort of communal or club ownership with cars being taken up and put down as the user felt inclined, would alleviate some present-day problems; but others, perhaps more difficult to solve, would be created.

In considering possible design changes, there are many factors to take into account. There is the job the vehicle has to do, the number of passengers to be carried, and the sort of journeys to be made. These will influence the characteristics people demand in terms of comfort, versatility, safety, range, handling qualities and so on. We have tried to take into account not only present likes and dislikes of the public towards features of car design, but also the need to adopt standards that are likely to reflect future, rather than present, circumstances.

Personal transport now serves many purposes in towns, from the regular individual commuting journey, to the less frequent social outing of a family. The large number of cars driven daily into city centres with only one occupant suggests that there is considerable scope, in terms merely of the pattern of personal transport journeys, for a single-seat vehicle. We have considered whether its disadvantages of limited use and carrying capacity are worth the space-saving advantages. At the same time, there is clearly a demand for multi-seat vehicles – and they may, in practice, offer advantages in terms of the space needed per person. The substantial number of business and shopping journeys which make up, for example, nearly a quarter of all journeys into Central London,[1] gives some indication of the need for luggage space. There is also often a need to leave personal possessions in cars.

Of great significance for a town vehicle is the average length of journeys into town centres. In 1961, average car mileage for all purposes was 135 miles a week, and in London it was only 117 miles,[1] and the average car journey to work was 5½ miles.[2] So a vehicle of comparatively limited range could meet many journey needs in towns.

But design objectives must be subject to engineering feasibility, both human and mechanical. We have therefore gone on in this Chapter to translate design objectives into engineering requirements and to test the overall engineering feasibility of the result. We have not thought it our job, neither have we attempted, to design an 'ideal' town car. But having arrived at certain design requirements, we have satisfied ourselves that they are capable of engineering solution.

A specialised town vehicle would, by definition, be less versatile than a present-day car. The only justification for it would be the off-setting benefits it could provide. We have shown that the full space-saving benefits of small size and uniformity in a particular type of vehicle can be obtained only by segregation from other vehicles, both on the move and when parked. In trying to assess

(1) See *London Traffic Survey*, (1962) vol. 1, chapter 6. L.C.C. 1964.
(2) *Motor car ownership and use*, Economic Trends, No. 116, June 1963 HMSO, monthly.

the benefits from a specialised town vehicle, we have considered how segregation might be appropriate for its use. To relate this to practical conditions, we considered, simply as an illustration, the segregated use of specialised vehicles in Central London.

3.1 Vehicle characteristics

Vehicle characteristics can be divided into two sorts – those that the user will more obviously demand – seating capacity, convenience of use, comfort, weather protection, economy and so on; and those, such as road-holding and the handling characteristics generally which, although basic to the performance and eventual success of a vehicle, are perhaps less obvious to the potential customer. Meeting both sorts of requirement is clearly essential.

As living standards rise, people pay more attention to comfort. It seems likely that most vehicle users will demand full weather protection, comfort in summer and winter, ease of driving and parking under town conditions, attractive design, good overall performance, light but positive handling, good all-round visibility and ease of entry and exit. These requirements have not, of themselves, led us to reject the possibility of a very unconventional form of vehicle. People might be prepared, for town purposes, to travel standing up or in a 'bar stool' style. But such arrangements seem to offer no obvious advantages in the design of a vehicle or in reducing traffic problems and we have not pursued them further.

It is not easy to define in objective terms such things as safety, road-holding and general handling and it is still less easy to define the standards that will be appropriate in one or two decades' time. Any standards set must be a matter of judgment. But in our opinion, the characteristics of any vehicle for future use should be at least as good as the best current practice. We have taken this as our standard. But we hope that, in many respects, it will be possible in future to improve on the best standards of today.

3.1.1 The two-wheeled vehicle

Under present conditions, two-wheeled vehicles generally take up less space than three- or four-wheeled vehicles, both in traffic and when parked. But we do not consider that two-, three- and four-wheeled vehicles need have the relative sizes, nor make the relative contribution to traffic congestion, that they do today. We have, therefore, considered the two-wheeled vehicle from the point of view of its own particular characteristics.

Present-day two-wheeled vehicles, whether bicycles, mopeds, scooters or motor cycles, are not self-balancing and there are limits to the standard of comfort and weather protection that they offer. These disadvantages are particularly significant in wet and very cold weather. But full weather protection could probably be provided on two wheels and stability could be improved in several ways. Thus it might be possible to develop a fully enclosed motor cycle with the seating and controls so arranged as to make the centre of gravity of the vehicle a good deal lower than with contemporary two-wheelers. It might also be possible to develop balancing skids or wheels which were let down automatically so as to give stability at low speeds or when standing still. Such developments might make the two-wheeler intrinsically safer than it is now. Even so, stabilisation by skids or auxiliary wheels would not result in a fully self-balancing vehicle. Except at low speeds, the vehicle would still have to be balanced by the driver so that many people who rely on personal transport in towns would in our view be unwilling or unable to use it. Moreover, the fitting of some stabilising device would be likely of itself to reduce somewhat the present size advantage of the two-wheeler.

The advantages in cost, manoeuvrability and road space which a fully weather-protected two-wheeler would enjoy over three- and four-wheelers would not, in our view, be so large as to offset the advantages in safety, comfort and versatility in use of a self-balancing vehicle. Although, therefore, we do not think that two wheels provide the best configuration on which to base a town vehicle for general use, we think that suitable two-wheelers should be allowed the advantage of any privileges that might be available to specialised town vehicles with more than two wheels.

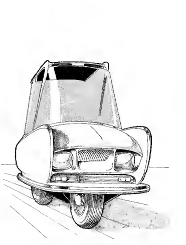


Plate 3–1 'It might be possible to develop a fully enclosed motor cycle'

3.1.2 The three-wheeled vehicle

The three-wheeled configuration is traditionally associated with modest size, ease of parking and good manoeuvrability These are characteristics desirable in a town car But the three-wheel layout has disadvantages in terms of cornering stability With a self-stabilised vehicle, such as a three-wheeler or a four-wheeler, stability against turning over on corners is obtained by making the track sufficiently wide in relation to the height above ground of the centre of gravity Lateral stability is improved by lowering the height of the centre of gravity and by increasing the effective track. For a three-wheeled car, the effective track is less than the actual track[3] so that, in comparison with a four-wheeled car, a three-wheeler will either have to have a wider track to achieve the same lateral stability, or else be less stable at any given width On the grounds of stability, the four-wheeler is therefore in general to be preferred as the basis for a car in which it is desired to keep the width to a minimum If the centre of gravity of a vehicle can be made low enough, a three-wheeler can, of course, be made with a narrow track and still achieve an entirely adequate stability In practice this situation is likely to arise only with some very unusual weight factors, such as might occur with a vehicle powered by storage betteries, the possibility of which is discussed in Chapter 10

A three-wheeler built to a conventional symmetrical layout has less disposable interior space than a four wheeler of comparable length and track. This disadvantage might be overcome by using an asymmetrical wheel layout, but the problem of achieving sufficient track width would then be accentuated and difficulties over weight distribution might also arise.

3.1.3 The four-wheeled vehicle

Both two-wheelers and three-wheelers can offer advantages over the four-wheeler in manoeuvrability and cost. They offer less freedom of internal design. But given the importance of minimising width for town traffic conditions and the advantage of similarity of handling compared with ordinary cars, we think that the four-wheel layout provides the best basis for a specialised town vehicle. We therefore adopted this layout for our feasibility design study.

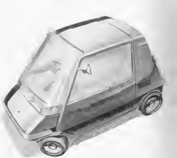
3.2 The pattern of ownership and use

Many people take a pride in owning a car Yet personal ownership is by no means essential to car use. We have looked at other possibilities because they would have considerable implications for vehicle design. As most journeys in town centres are short and many of the cars used for them remain parked and unused for much of the day, some form of personal very short-term hire – in effect a self-drive taxi – with the prospect of more intensive use of each vehicle throughout the day, seemed worth considering

A common suggestion[4] is a system of pool ownership or club hire. This involves a fleet of cars being available within a defined area, with all participants in the scheme having access to cars for journeys within the area This could have big parking advantages because the high utilization of each vehicle that would theoretically be possible would reduce the need for parking space and because car parks would not have to be able to deliver any particular car; supplying the first available vehicle would be all that was needed. But the casual and varied use to which the vehicle would be put by drivers of widely different skills would demand more rugged construction than for a vehicle for private use; it would be necessary to equip the vehicle with a reliable method of recording or obtaining payment for use; there would be formidable problems of fraud, mis-use and legal liability; and in practice, ensuring that vehicles were available where they were wanted might prove very difficult. Although pool systems have some advantages, the benefits from specialised town cars do not depend on their being used in this way.

Plate A

Plate B



Plates 3–2(A–E) Many attempts are made to design and build town cars

[3] If T is the actual track of a three-wheeled vehicle, L the wheelbase, and x the horizontal distance between the centre of gravity of the vehicle and the two-wheeled axle, then the effective track, Te, is given by

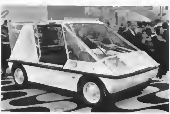
$$T_e = T\left(1-\frac{x}{L}\right)$$

[4] Made, for example, by the Battelle Institute of Geneva, StaRRcar and Rank.

Plate C

Plate D

Plate E



A pool system could be linked with the sort of interchange arrangements often suggested as part of the use pattern for special town cars. Thus it is sometimes suggested that ordinary cars should not be taken into the congested parts of towns but should be exchanged at conveniently-sited car parks for special town cars, possibly operated on a pool system. We think that there would, in practice, be very great difficulties in designing a practical interchange layout that contributed to convenience of car use.[5] However, interchange arrangements would not have any implications for the design of a specialised town car, beyond those already mentioned in connection with pool ownership.

Accordingly, we envisage a pattern of operation in which town cars would be kept at home and used mainly, but not exclusively, for journeys into town centres. In towns, advantage would be taken of any special facilities for town cars, including the use of segregated road or parking space, but town cars would have to be useable in mixed traffic as well. We have proceeded with our design study on this basis. Any interchange system or short-term hire of town cars would operate within this general framework.

3.3 Public acceptability and social implications

Unorthodox small cars[6] are not popular in this country. For example, over the past six years, three-wheeled cars have made up no more than 4% of the total number of licensed cars with engines of less than 1,000 cc. As most existing unorthodox small cars are three-wheelers, we decided to find out whether the licensing figures reflected a general dislike of unorthodox small cars or a dislike merely of three-wheelers. We used a public opinion survey which also sought to determine the nature of objections to very small cars and whether attitudes varied between different social groups.

The survey showed that unorthodox small cars were rated poorly for comfort and safety. They were also disliked simply for their size, though they were more highly rated for economy of running. There was very little variation in the attitudes of different occupational age and income groups or between the sexes. For the great majority, the economy of present-day unorthodox small cars was heavily outweighed by other considerations; those who favoured them were mainly concerned with economy.

The survey has two important implications for the specialised town car. Although the general public is becoming increasingly aware of the problems of traffic congestion, the present unpopularity of unorthodox small cars is such that a worthwhile incentive will be needed if small town cars are to become generally attractive. This conclusion is reinforced by other findings which show that car owners generally choose the same size or larger rather than smaller models as their next purchase. Secondly, the survey shows what the general public dislikes about unorthodox small cars, and indicates clearly the characteristics to be avoided in the design of a town car. This reinforces the conclusion reached in section 3.1 above that on the grounds of stability, safety and comfort a four-wheeler is likely to prove more acceptable than either a two- or three-wheeled vehicle.

A specialised town car would be, by definition less flexible in its use than a general purpose car. On this account, it would tend to be less popular. But a significant trend, which we think will be fundamental to the popularity of the town car, is the rapidly increasing number of families with more than one car. Ten years ago, under 2% of car-owning households owned more than one car. Now nearly one in eight of car-owning households have more than one car. As levels of income continue to rise, we expect

[5] This is fully discussed in Appendix B.
[6] By unorthodox small cars we mean, for example, those popularly known as 'bubble cars', both three-wheel and four-wheel. We do not mean the popular small cars now in use in large numbers in this country.

the proportion of multi-car households to increase significantly and the total number to rise even more. This provides a framework in which the specialised town car could well be increasingly accepted as an additional car. The family's main means of personal travel may remain a general all-purpose car, but second and subsequent cars within the family may reflect more closely the journey needs of one or two members. This could affect radically the general popularity of small town cars, as additions to, rather than as replacements for, the ordinary family car.

Some indication of the scope for a town car is given by the number of journeys made to work daily into town centres by personal transport. The figures for various provincial towns are

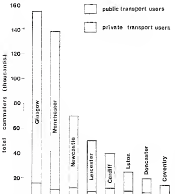


Figure 3:1 Commuters into various provincial towns (1962)

given in figure 3:1. The larger the town, the smaller is the proportion of commuters using private transport This suggests that there is already, in larger towns, a considerable potential demand for commuting by private car that is frustrated not so much by the present level of car ownership as by the difficulties of car use under present-day traffic conditions. We conclude that although general purpose cars are the present choice of most car-owners, and unorthodox small cars are generally unpopular, the introduction of a small car that made it possible for more people to travel by car to town centres might well constitute a major new factor in the potential popularity of such cars

Deciding on what is the best sort of car will be determined by not only the types of journey to be made, but also the traffic and engineering aspects of the cars themselves. These are discussed below

3.4 The design parameters

The design features of any vehicle are interrelated. In this section we consider, in the light of the factors already mentioned, the desirable dimensions for a town car, taking into account human dimensions and vehicle stability We consider the performance required and hence the power needed, and bring all these factors together to test the overall engineering feasibility of the whole.

3.4.1 Human dimensions

As a passenger, an adult needs at least 21 in of shoulder space A driver needs to be able to move his arms and legs more freely and so needs rather more room. So an interior width of something over 4 ft is needed for the safety and comfort of a driver and passenger sitting side by side, although a smaller width could be enough if the seats were offset so that the driver and passenger were not shoulder to shoulder There is no significant engineering or traffic advantage in limiting the internal height inside a town car – and, in fact, some advantage, from the user's point of view, in having generous head room. The interior height of most existing small cars lies in the range 3 ft 6 in to 3 ft 10 in and we have allowed a height of up to 4 ft. As length of a town car is also not of critical significance, we see no need to reduce leg-room below that now provided.

3.4.2 Vehicle stability

The need for adequate stability limits the minimum dimensions of both track and wheelbase. These do not of themselves ensure good stability, as this depends also on many other aspects of vehicle geometry, suspension and so on But we have attempted to establish minimum track and wheelbase dimensions which, coupled with good design elsewhere, would result in good handling and stability We have considered the two main elements of vehicle stability – sideways (or lateral) and fore and aft (or longitudinal) stability.

3.4.3 Lateral stability

Defining all the factors that go to fix the minimum vehicle width needed for lateral stability is difficult; they include the height of the centre of gravity, the distribution of weight within the vehicle, the forces developed when cornering, the suspension, wheel and tyre characteristics and the ability of the vehicle to ride over small obstacles. However, for the purposes of determining minimum dimensions, it is probably adequate at this stage if lateral stability is considered solely in terms of the ratio of the height above ground of the centre of gravity to the effective track width.

The basic determinant of the necessary level of lateral stability is the maximum side force which a vehicle may be required to withstand. This force is made up of the effects of crosswinds and the sideways force exerted by the vehicle itself in swerving or cornering. A vehicle able to withstand a lateral acceleration of 1·0g.(7) would be very stable indeed. There would be very little risk of turning over on an unobstructed road, as the vehicle would normally slide first. This represents an almost ideal standard.

The minimum desirable standard is very much a matter of opinion. In our judgment, a vehicle able to withstand a lateral acceleration of 0·75 g without overturning would be acceptably safe. We have taken this as the limit in arriving at a safe maximum ratio of the height of the centre of gravity to the effective track width.

The relationship between lateral stability and lateral acceleration is shown graphically at figure 3:2. Lateral stability decreases as lateral acceleration increases, until the point is reached where the vehicle would roll over. Assuming a centre of gravity height of 20 in (which is achieved on existing small petrol-engined cars, and we think likely to be repeated in any town car) and

taking a sideways acceleration limit of 0·75 g, leads to a minimum track of 30 in.

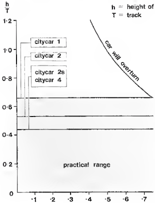


Figure 3:2 Maximum lateral accelerations before overturning

3.4.4 Longitudinal stability

The basic factors in longitudinal stability can also at this stage be taken as the ratio of the height of the centre of gravity to the wheelbase of the vehicle, and the position of the centre of gravity in relation to the front and rear axles. The former determines the transfer of weight to the front wheels during braking and must be such as to leave enough weight on the rear wheels to maintain effective ground contact and thus ensure directional stability. The fore and aft position of the centre of gravity determines the static weight distribution between the axles and must be such that enough adhesion will remain on the driving wheels to allow any required performance on any assumed gradient or road surface.

To establish practical limits for these basic factors, we assumed a coefficient of road/tyre friction[8] of 1·0, a rolling resistance[9] of 2%; and that the steepest gradient to be negotiated would be 1 in 5 (such as on a garage entrance ramp). Though somewhat arbitrary, these assumptions allow reasonable account to be taken of the limits imposed by dynamic conditions. The graphs in figures 3:3 and 3:4, for front and rear wheel drive respectively, relate longitudinal stability to the weight distribution between the front and rear axles. They show the limits outside which a vehicle would overturn forwards or backwards when braking, and outside which it would be prevented, by wheel spin, from climbing a 1 in 5 gradient.

Theoretically, any design parameters falling within the area of the curve in figures 3·3 and 3·4 would provide adequate longitudinal stability. The practical limits are, however, further restricted by detailed design considerations and we consider that the fore-and-aft static weight distribution should result in no axle carrying less than 30% of the weight.

Arriving at these weight distribution and dimensional limits has involved judgment and assumptions and the numerical values we specify cannot be regarded as rigid requirements. But we considered an assessment in numerical terms to be essential to an engineering feasibility study.

3.4.5 Dimensions

The uses made of cars in towns can support the cases for a single-seat vehicle and for a multi-seat vehicle. We have therefore considered vehicles with up to four seats. Figure 3:5 shows some of the many possible seating layouts. We could see little value in some of these arrangements and decided the most useful and challenging possibilities were:

(a) single seat,

(b) two offset seats,

(c) two seats side by side,

(d) four seats, forward-facing, in two rows of two.

For convenience, we have called these four vehicles Citycars 1, 2, 2S and 4 respectively.

Combining the stability and ergonomic requirements[10] and the seating layouts leads to the results set out in figure 3·6. We have examined more closely the engineering feasibility of these layouts to bring out the passenger-carrying ability, general performance, stability and traffic advantages of each car, so as to enable their capabilities and limitations to be compared.

[7] See glossary.
[8] See glossary
[9] See glossary
[10] See glossary.

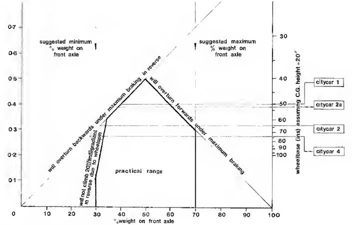


Figure 3:3 Limitations on weight distribution—front wheel drive vehicles

h = height of C.G.   L = wheelbase

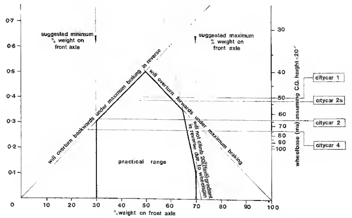
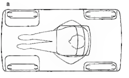
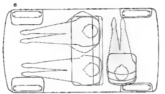
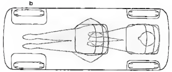
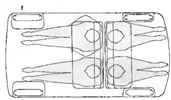


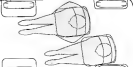
Figure 3:4 Limitations on weight distribution—rear wheel drive vehicles

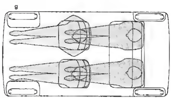


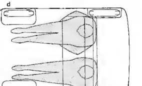












a Single seat - *Citycar 1*
b Two-seat tandem, forward facing
c Two-seat offset (or staggered) seats - *Citycar 2*
d Two-seat side by side - *Citycar 2S*
e Three seat, two forward facing one sideways behind them
f Four-seat, back to back
g Four-seat, forward facing - *Citycar 4*

Figure 3:5 Seating layouts for very small cars

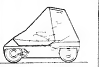
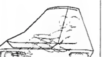
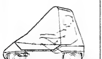
Citycar	Dimensions	Power and transmission	Weight distribution	
			Front wheel drive	Rear wheel drive
Citycar 1 	Track 40" Wheel base 50" Length o.a. 70" Width o.a. 36" Height o.a. 48" Ground clearance 4" Turning circle, kerb-kerb 17 Laden weight, lbs. 850	Capacity c.c. 350 No. cylinders 2 Output b.h.p. 15 to 20 Max torque lbs.ft. 18·5 – 25·5 Max. revs 6,000 Engine cooling water Transmission auto Ratios 4:1 to 1:1	Fully laden Front 57% Rear 43%	Fully laden Front 40% Rear 60%
Citycar 2 	Track 38" Wheel base 56" Length o.a. 82" Width o.a. 44" Height o.a. 52" Ground clearance 4" Turning circle kerb-kerb 18 Laden weight, lbs -2 up 1140	Capacity c.c. 550 No. cylinders 2 Output b.h.p. 22 to 27 Max torque lbs.ft. 27 – 33 Max. revs 6,000 Engine cooling water Transmission auto Ratios 4:1 to 1:1	Fully laden Front 52% Rear 48%	Fully laden Front 40% Rear 60%
Citycar 2S 	Track 45" Wheel base 52" Length o.a. 78" Width o.a. 52" Height o.a. 51" Ground clearance 4" Turning circle, kerb-kerb 18 Laden weight lbs -2 up 1,140	Capacity c.c. 550 No. cylinders 2 Output b.h.p. 25 to 30 Max. torque lbs.ft. 31 to 37 Max. revs. 6,000 Engine cooling water Transmission auto Ratios 4:1 to 1:1	Fully laden Front 54% Rear 46%	Fully laden Front 42% Rear 58%
Citycar 4 	Track 45" Wheel base 70" Length o.a. 94" Width o.a. 52" Height o.a. 52" Ground clearance 4" Turning circle kerb-kerb 21 Laden weight lbs -4 up 1,710	Capacity c.c. 650 No. cylinders 4 Output b.h.p. 30 to 35 Max. torque lbs.ft. 27 to 42·5 Max. revs. 6,000 Engine Cooling water Transmission auto Ratios 4:1 to 1:1	Fully laden- 4 up Front 50% Rear 50%	Fully laden- 4 up. Front 42% Rear 58%

Figure 3:6 Outline specifications for Citycars

3.4.6 Power required

As a result of the conclusions reached in Chapter 2, we have taken as our minimum requirements for a citycar the ability:

(a) to maintain speeds of at least 40 mph on the level and 25 mph up a gradient of 8% (1 in 12½);

(b) to accelerate at a rate of at least 4 mph per second up to 40 mph (i.e. 0 to 40 mph in 10 seconds);

(c) to climb a gradient of 1 in 5.

We also consider citycars would need automatic transmission to increase uniformity in performance.

Figures 3·7 to 3.10 show the relationship between power and performance for the four types of citycar based on the performance characteristics of conventional internal-combustion engines. As the graphs show, any car that met our acceleration requirements would, almost inevitably, be capable of a high top speed. The stability criteria we adopted are appropriate to town speeds, but it would be important that any car capable of, say, 70 mph had a good margin of stability over and above the minimum standard we have adopted. The margin of lateral stability on Citycar 1 and Citycar 2, while perfectly adequate for town speeds, might not perhaps be sufficient at speeds over 60 mph. It would be possible to meet this difficulty by restricting the top speed artificially.

Noise and air pollution are particularly important in a vehicle intended for high density town use. We suggest in Chapters 8 and 9 that the conventional four-stroke petrol engine can be made perfectly acceptable in these respects for a town car and we have therefore assumed its use in our citycar studies. The possibilities of other power units are discussed in Chapter 10.

The conclusions we draw from these preliminary studies is that specialised one-, two- and four-seater cars could be designed to meet the dimensions and specifications we have adopted, could provide good stability and handling and have a performance that would achieve efficient use of crowded town road space. In meeting the requirement to accelerate from rest to 40 mph in 10 seconds, top speed and hill climbing would be better than needed.

3.4.7 Possible vehicle costs and market

We have attempted to compare the costs of the one-, two- and four-seater versions. Any exercise in arriving at actual prices a long way ahead is obviously difficult. But such costings as we have been able to make suggest that the differences in selling price between the various models of citycar would probably be quite small. Citycars 2 and 2S might cost about 7% less than Citycar 4, and Citycar 1 about 11% less than the 2-seater models, so that the single-seater would cost about 17% less than the four-seater. To the extent that they are smaller and lighter, citycars could be expected to be rather cheaper than existing small saloon cars produced on a similar scale. But cost is only one factor in the choice of any car. Citycars could offer greater scope for individual travel in cities and their price might not be a dominant factor in determining their sales. The market is likely to be determined more by the facility that the vehicle and its operating circumstances offer than by the appeal of the vehicle in isolation.

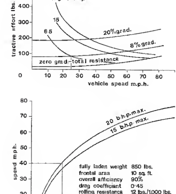


Figure 3:7 Performance and power requirements for Citycar 1

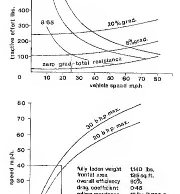


Figure 3:8 Performance and power requirements for Citycar 2

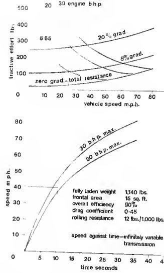


Figure 3:9 Performance and power requirements for City-car 2S

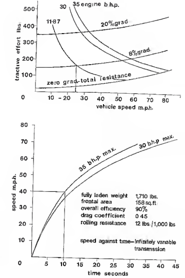


Figure 3:10 Performance and power requirements for City-car 4

3.5 The benefits

A specialised citycar would be less attractive for general use than the present all-purpose car. The only justification for this would be the benefit to be obtained under town conditions; these stem chiefly from the reductions in space needed when on the move and when parked. The possible benefits from reduced air pollution are discussed at the end of Chapter 9.

3.5.1 The road space savings per car

We suggested in Chapter 2 that to get the most benefit out of small cars they should be segregated from other traffic. So we have considered the road space needed by various types of car under conditions of segregation from other traffic (i.e. in uniform traffic) as well as in mixed traffic conditions. We have based this calculation on the 'envelope' concept described in section 2.1 but have also made some allowance for the effect of lane width on road capacity. The results are in figure 3:11 which shows the number of cars of various types able to use a given area of road space at a speed of about 30 mph. This illustrates the advantages of small cars in segregated conditions – about 170 Citycars 4 or 220 Citycars 1 could use the space now occupied by 100 present-day average-sized cars.[11]

3.5.2 The road space savings per person

The road space needed per person is more important than the road space per car. Cars usually carry only one or two people, including the driver. In 1961, the national average on weekdays was about 1·7[12] persons per car, but the average for journeys

(11) However, provisional calculations indicate that at a speed of 40 mph the number of eg Citycars 1 which could use the space now occupied by 100 average-sized cars would be about 25 fewer but if the speed was only 20 mph the number would be about 45 more.

(12) *Motor car ownership and use*. Economic Trends, No. 116, June 1963. HMSO, monthly.

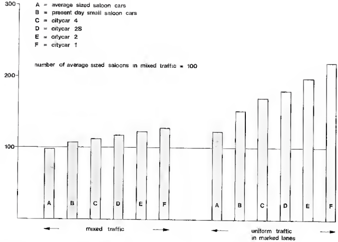


Figure 3:11 Numbers of cars able to use a given area of road space

on business and to and from work is a good deal less. In Central London, average occupancy is about 1·4 persons per car.[11] Figure 3:12 is based on observations in Central London. It shows that the driver was the sole occupant in two cars out of three; there were no more than two people in fourteen cars out of fifteen; and only one in fifty carried four or more people. So on weekdays more than two-thirds of all journeys in Central London – and probably in other large towns as well – could be made in single seaters, and over 93% could be made in two-seaters.

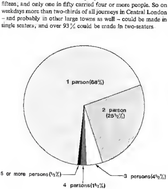


Figure 3:12 Car occupancies in Central London

[11] *London Traffic Survey* (1962), Vol. 1, Chapter 6. L.C.C. 1964.

Figure 3:13 illustrates the benefits, in terms of people carried, of using smaller cars in mixed traffic and when segregated, as compared with present types of cars. It is the counterpart of figure 3:11, being related to numbers of people and not to numbers of cars. It takes as its starting point the road space needed by 100 people travelling in averaged-sized cars in mixed traffic, and sets out the number of people that could be moved in the same amount of road space in present-day small cars and in different types of citycar under both mixed and uniform traffic conditions.

The calculation is based on the known present occupancy of cars and not simply their maximum capacity. The result shows the progressive advantages of smallness down to two-seaters, especially in uniform traffic. Twice as many people could be moved in Citycars 2 in uniform traffic as can now be moved in averaged-sized cars in mixed traffic. The diagram also shows the relative disadvantage, in terms of carrying capacity, of the single-seat vehicle, more of which would be needed to cope with a given number of people.

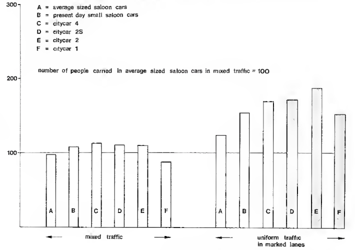


Figure 3:13 Numbers of people likely to be carried on a given area of road space by different types of car

3.5.3 The parking space savings

Figure 3:14 shows the parking advantages of using small cars, provided that parking space were constructed or laid out specifically for each type of car.

The parking advantages of small size increase progressively right down to the single-seater. The ability to pack more small cars into the limited amount of room that can reasonably be devoted to car parking in town centres and other employment areas is an important factor to be weighed in considering the contribution of single- and two-seater cars to the solution of the urban traffic problem. With growing car ownership saving in car parking space can also be expected to become increasingly important in high density residential areas.

3.5.4 The total space savings

We have attempted to calculate a single index of the overall benefits from each citycar by creating, in effect, a weighted average of the road space and parking space benefits. We have based this on the average commuting and business use that is made of cars, on average traffic speeds in towns and on the average length of the working and commuting day. The results are illustrated in figure 3:15. It shows the overall benefits in space saved by citycars and that the savings are such that the use of these cars, with facilities designed for them, would enable space in towns to be used about twice as efficiently – in terms of numbers of people for whom car space can be provided – as when the space is used by present-day cars, in general-purpose car parks, and in present traffic conditions. Rather more than half this benefit would be obtainable by providing segregated facilities for the use and parking of existing small cars.

3.6 Segregating citycars from other traffic

Commercial vehicles up to 8 ft 2½ in wide, carrying loads up to 9 ft 6 in wide, and weighing up to 32 tons laden, are allowed without restriction on most ordinary roads, and over-bridges are usually built with clearances of 16 ft 6 in below them. Citycars would be 3 ft to 4 ft 4 in wide, could weigh one-third to three-quarters of a ton fully laden and be under 4 ft 6 in high. They could therefore operate on much narrower lanes and lighter road structures, and with much lower overhead clearances than are allowed for ordinary vehicles. They would need only 7 ft lanes and perhaps even less for the single-seater.

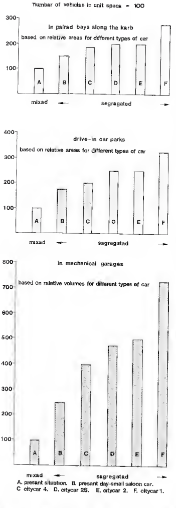


Figure 3:14 Number of cars able to be parked in a givan parking space

Segregation of citycars from other traffic could be achieved on existing streets or by constructing new roadways. In some wide streets it might be possible to set aside one or two narrow lanes for citycars, thereby increasing the vehicle capacity of the street. But there would be traffic engineering difficulties about this, particularly at junctions, as well as some reduction in the space available for larger vehicles. A better approach might be to make more use of existing under-used capacity. Thus although the main road network in nearly all towns is saturated at peak hours, some surplus capacity exists even then in side streets, many of which are used almost exclusively at present for parking. Attempts are sometimes made to utilize this capacity by using these streets in one-way systems but often they are unsuitable for the heavier vehicles which would be diverted on to them. Even if they are wide enough, there may be serious amenity objections to their use by heavier vehicles, particularly if the streets are residential. The possibility of using this additional capacity by reserving some of these streets for the exclusive use of citycars (apart from delivery traffic) is more attractive. Few would be too narrow for the use of citycars and amenity objections would be greatly eased, partly by reason of the small size and comparative silence of the vehicles and partly because they would be there mainly at peak hours and hardly at all at night. The main problems would be created at the junctions with the main road network but the use of lightweight over-passes or shallow under-passes to achieve grade separation[14] might provide a solution that was financially acceptable and which minimized any loss of amenity.

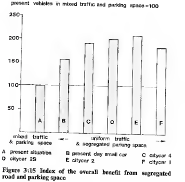


Figure 3:15 Index of the overall benefit from segregated road and parking space

(14) See glossary.

3.6.1 Segregating by new roadways

Setting aside some existing street capacity might not make available enough road space to justify using special citycars. Over the period we are considering a good deal of money is going to be spent on road-building in towns and we have therefore explored briefly the possibility of some resources being used to provide new roadways exclusively for citycar use. This would enable full advantage to be taken of the light weight and low height of citycars, which could be best exploited by providing roads tailor-made for them. This could be particularly appropriate in town centres where the existing road system is already over-loaded.

In existing cities, difficulties of finding new alignments through built-up areas led us to consider whether segregation could be obtained by using a different level on existing street alignments. Though under-passes might form part of a reserved roadway system, there would be serious and probably insuperable engineering difficulties in carrying the system generally underneath existing roads, because of the public utility services already there. Expense apart, we do not foresee reserved roadways generally being put underground. This points to a network that would at least in part be elevated, linked at intervals to the ordinary road system.

To study the traffic and civil engineering feasibility of such a network we needed some indication of the number of journeys that might be made on it under some practical conditions. We used as an example an area of inner London. Forecasts of car journeys for 1981 were assigned, by computer, to the existing roads and to the new network on the basis that each car would take the route that offered the quickest journey. In drawing up a route network, we assumed that London would by then have a motorway (the 'motorway box') encircling the centre at about 4 to 6 miles radius. The new network would link this directly with the City, the West End, Westminster and Whitehall. It would also be linked to roads in the central area and, perhaps, also directly to car parks. But, otherwise, it would form a self-contained system, capable of carrying at least 1,800 small vehicles an hour on each lane, at speeds of up to 40 mph. The narrow lane widths required, as well as the lightness of the load to be carried would enable the system to be carried along existing streets on their present alignments, without the extensive re-development and severance of neighbourhoods usually associated with major urban road projects.

We took first the fairly intricate network of figure 3:16. Although such a network would attract to itself nearly all Central London car traffic, the road space on a two-way system of this kind would be substantially under-used in many places. Moreover, although it would leave the ordinary roads free for public transport, lorries and taxis, and so enable this traffic to move much faster, there would be very severe traffic engineering problems at the many intersections. So we looked at the possibilities of a much simpler one-way network, again following existing street alignments but limited to routes on which traffic seemed likely to be heaviest; this is shown in figure 3:17. Such a scheme has obvious limitations. Many journeys would be longer – although the fewer and simpler junctions would allow higher speeds – but even so a lot of car traffic would be attracted to a network of this kind. Much detailed work, not justified in the context of the present study, would be necessary to establish the best network pattern; it would probably lie somewhere between the two cases considered. There seems little doubt that sufficient traffic capacity could be obtained by combining a system of overhead structures, for the most part carrying two lanes of traffic, but with short lengths of up to four lanes, with single lanes at ground level formed by reserving part of the existing roads.

The characteristics of citycars would allow overhead structures(15) to be much lighter, both in construction and appearance, than

Plate 3–3A 'Modern overhead footway'

Plate 3–3B 'General purpose overhead roads'

would be possible for a standard highway, or even for a road designed to carry ordinary cars and light vans. In the simplest terms the average vehicle loading would be about 60 lbs per sq ft, which is no more than one-third of normal highway loading. Even so, there would be difficulties to be overcome in adding such a structure to many existing roads. Some reduction in existing carriageway widths might have to be made to give room for the supports of the overhead ways. Foundations would have to take account of basements under footways, the substructure and foundations of adjacent buildings and the public utility services. The cost of foundations and of diverting services could be substantial and could, in many instances, be a determining factor in the choice of route and design of structure.

(15) We are indebted to the Bridges Engineering Division of the Ministry of Transport for the studies and designs of overhead structures.

For the structure, light alloys and other lightweight materials might prove desirable. But steel and concrete, especially in their latest forms, offer great strength and durability for small bulk. Plastic coating could obviate many of the present aesthetic and maintenance disadvantages of steel. In the future there might be scope for using light alloys or reinforced plastics in the decking. To minimise disturbance to traffic during construction, the structures would need to be pre-fabricated. Erection of the overhead structures themselves would be simplified by their comparatively light weight. With some designs, two 5-ton mobile cranes would be capable of lifting into place 70 ft lengths of overhead roadway.

Structures could run over either the existing footway or the centre of the existing road. Examples are shown in figures 3:18 to 3:22. The scale of these structures would be rather more akin to a modern over-head footway than to general purpose overhead roads. Not only would there be large savings in costs compared with general purpose urban motorways, but the structures would be practicable and acceptable in many places where full-scale motorways would not.

Special maintenance, recovery, ambulance and fire service arrangements would be needed, but should not create insuperable difficulties.

3.6.2 Segregated parking space

Providing segregated parking space would create no difficulties. On-street spaces could be laid out to suit any required dimensions and off-street car parks – ramp or mechanical – could be designed to take advantage of size limits on cars.

3.7 Summary and conclusions

In this Chapter, we have considered the principle design features of cars intended specifically for town use, their possible system of ownership and of use, their performance and the sort of highway and parking facilities that would be needed to get the most benefit from them. We attempt now to relate a specialised vehicle to the transport needs of towns.

We have postulated a personal transport system based on small vehicles probably powered by an internal-combustion engine and having one, two or four seats. The performance of these vehicles would be at least as good as most of today's family saloon models, and their handling and general safety characteristics would, in relation to the use we intend, also be up to good present-day standards. The top speed allowed in towns might be only 40 mph, but the vehicles would probably be capable of a good deal more. To meet as much as possible of the potential demand, any citycar should be four-wheeled but we see no objection to two- or three-wheeled versions, if they were preferred by the user, provided that they met the dimensional and other requirements.

We have assumed that some reserved road space would be set aside or new roadways built, and parking space provided, for the exclusive use of citycars. Initially, special facilities would inevitably be limited – perhaps to reserved roadways at the worst congestion points and to special parking facilities. As citycars numbers grew, it would become more and more worthwhile to increase the amount of space available for them until ultimately a comprehensive network of roadways and parking space had been built up. Some of the segregated running space could be provided by the building of a new lightweight overhead network which, if constructed over or alongside existing main roads, could minimise the severance and other disturbance problems associated with new road alignments in existing towns. But, at least in some places, segregation could probably be achieved by setting aside existing road space.

Citycars could be garaged at home and driven on the ordinary road system, moving on to the segregated space where this was available. At or near its destination, the citycar might be parked in an off-street garage linked with the segregated roadway or it might re-enter the ordinary street system to complete its journey, ending, as now, parked on or off the street. Certain dimensions and performance requirements would be laid down and would have to be met by any vehicle seeking to use the exclusive citycar facilities. This would not necessarily mean monopoly manufacture under Government auspices; manufacturers could have complete freedom of design, within the overall specification. Citycars could be privately owned or else hired, for short or long periods.

With segregation, citycars would make use of a given space in a way that would enable twice as many people to travel by car as could do so in present cars under present traffic and parking conditions.

Small unorthodox cars are now generally unpopular. But we think that the increasing number of multi-car families and the possibility of a second car being related to a more specialised type of journey, will increase the scope for, and acceptance of, a vehicle that would inevitably be less flexible in its use than the general purpose car of today. Even so the use of citycars would still not come about without an incentive. There would be the traffic advantage,[16] in terms of savings in journey time – which might be very significant – and perhaps greater ease of parking, that the citycar could offer. It is difficult to say whether this could be sufficient to lead to the extensive use of citycars. If not, some additional financial or tax incentive would be needed; this would probably be justified by the savings to the community as a whole through the smaller space needs of citycars. There is, moreover, an increasing prospect that in future individual car users will be expected to bear the social costs of using and parking cars in congested areas. This would provide a new framework of incentives within which the use of much smaller cars could easily and appropriately be promoted.

We have throughout this study considered one-, two- and four-seater vehicles and have assessed separately the engineering feasibility of each. Our decision not to reject any one of these

Plate 3–4 Reserved cycle track at Stevenage

(16) That a reserved roadway system can be attractive is illustrated by Stevenage, where a completely segregated system of cycleways connects the residential areas, town centre and industrial parts of the New Town. These cycleways are reserved for bicycles and mopeds (up to 50 cc engine capacity). It is claimed that journeys can be made more quickly in Stevenage by moped than by any other means. 16% of commuters to this industrial area use mopeds or bicycles, which is a far higher proportion than elsewhere.

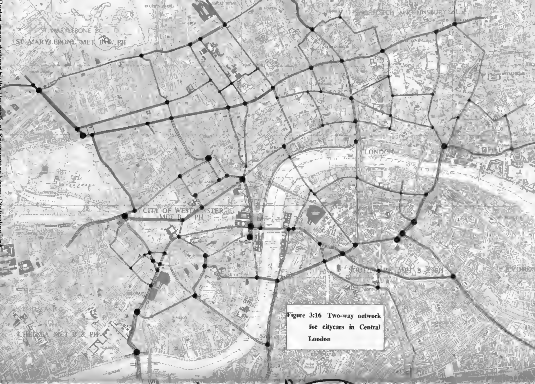


Figure 3:16 Two-way oetwork for citycars in Central Loodon

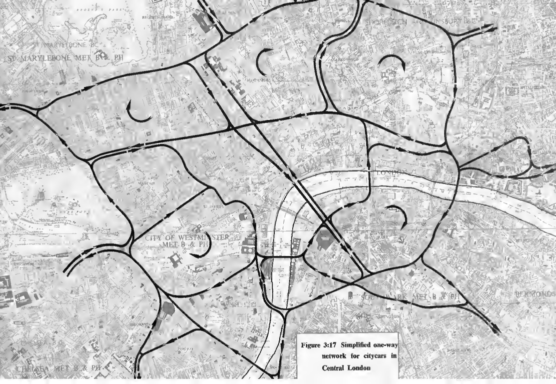
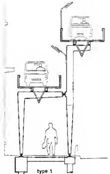
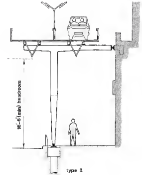


Figure 3:17 Simplified one-way network for citycars in Central London



elevated carriageways of different levels

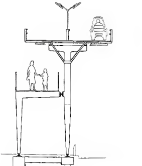


elevated carriageways part supported from adjacent buildings

structure type 1 to 3
span range 45–75 ft

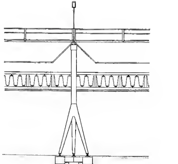
description

The steel superstructure is carried on bored pile foundations with reinforced concrete caps. The 7ft carriageways are supported on longitudinal space frames and have ribbed plate decks with epoxy resin wearing surfaces.
The safety barriers are of lightweight alloy sections or strained wires.



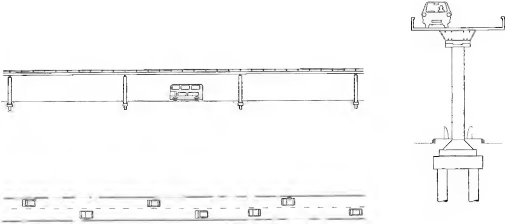
elevated carriageways and under-level pedestrian way

type 3



view of support from road

Figure 3:18 Sectional drawings of overhead road structures



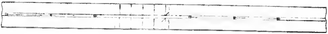
structure type 4
span range 50–120 ft

description

The steel beam and columns are carried on bored pile foundations with reinforced concrete caps. The deck with 7ft. carriageways is of precast concrete or reinforced plastic construction with an anti-skid epoxy resin wearing surface.

Safety barriers are of reinforced plastic sections.

Figure 3:19 Length of overhead road structure showing elevation, plan view and sectional drawing (structure type 4)



structure type 5
span range 90–200ft

description

The steel stayed girder spine beam is supported by steel columns carried on bored pile foundations with reinforced concrete caps The lightweight alloy cantilever deck has 7ft carriageways with anti-skid epoxy resin wearing surface. Safety barriers are of lightweight alloy sections.

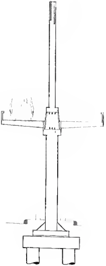


Figure 3:20 Length of overhead road structure showing elevation, plan view and sectional drawing (structure type 5)

configurations has been taken deliberately because we think the basis of choice should go wider than our terms of reference. For example, a single-seat citycar has some traffic and social disadvantages. The traffic disadvantage is that, because it provides for only one occupant, more vehicles, and hence more road and parking space are needed for a given number of people than would be necessary with a two or four-seat vehicle. But for business use, or for the morning and evening journey to and from work, this disadvantage would be slight, because these are the types of journey that drivers often make by themselves. But it would be less attractive for general use. The significance of this can be assessed only in the context of the whole transport system – public and private – of a town. Thus, if there were any question of restricting the use of conventional cars in congested parts of cities, a system which permitted access by single-seat cars and denied the facility of the private car to those unable to drive, would seem to us quite unacceptable. Again if public transport were allowed to decline greatly, the social disadvantage of single-seat cars would be all the more significant. However, we visualise any citycar system to be a facility additional both to ordinary cars and to an effective public transport system. In these circumstances, the disadvantages of the single-seater would be less serious.

A two-seater with the seats offset, or staggered, by about a foot could offer the advantages of two seats with only a slight penalty in increased width. There could be some disadvantages in this design, but we are by no means sure they are significant enough to affect its great advantage of being the smallest vehicle capable of meeting most of the needs of urban car travel; and there would be compensating advantages – there would be some internal luggage space, and easy access to the driver's seat from the near side. It seems likely to offer under most journey conditions more efficient use of road space than any other form of personal transport we have considered. The side-by-side two-seat citycar might be slightly more attractive to users, and it uses road and parking space almost as efficiently as the two-seater with offset seats.

The four-seater would be big enough to meet all the normal requirements of a means of individual transport, yet be light and compact enough to run on lightweight road structures. It would offer slight savings in highway space and rather more worthwhile savings in parking space, compared with most existing small four-seater cars. It could be more acceptable to users than a two-seater, but would not achieve all the space-saving benefits of the two-seater.

We have stressed that providing for the private car cannot be looked at in isolation from the general transport planning – and, indeed, even wider aspects – of a town. We touch briefly on the significance of this, in relation to the role for citycars, in our final conclusions.

4 Taxis

By taxis we mean professionally driven vehicles plying for hire at a metered fare, and operating within regulations, as distinct from either hire cars – which are booked privately in advance at a charge agreed between the operator and the hirer – or self-drive cars.

The taxi population of this country declined a good deal in the decade immediately after the Second World War, but has remained reasonably steady since 1960 at about 14,000 vehicles. In broad terms, half the taxis in this country are purpose-built vehicles, which are found predominantly in London, provincial taxis in the main being slightly modified medium or large saloon cars.

Although taxis represent only about a tenth of one per cent of all road vehicles they are used much more intensively than many other forms of road transport, and in some places form a significant part of total traffic.[1] Whereas on average, private cars travel under 20 miles a day, the London taxi's mileage exceeds 80 miles daily.[2]

In considering design trends in taxis we looked first at the respective needs of the user and of the operator and then considered the effect of regulation on design. Licensing was not designed to limit the number of taxis on the road – nor does it do so in practice. But it establishes a framework, regulating fares and vehicle standards, within which operators must work, so that it becomes virtually impossible to consider taxi design apart from this framework.

Plate 4-1 'The London taxi is the best known example of a purpose-built cab'

4.1 Users' needs

Taxis are used mainly for very short town journeys. The average length of the 150,000 or so daily fare-paid taxi journeys in the London area is just over two miles. Over two-thirds of the journeys are either to or from, or wholly within a central area of two miles radius.[3] The taxi offers a means of quick and easy personal door-to-door transport. Heavy baggage or parcels can be easily carried and the user does not need to know his way, nor find a space to park.

4.2 Operators' needs

The aims of the operator must be to meet and, if possible, stimulate demand. High vehicle utilisation is essential. He will, therefore, want a cab which is, above all, reliable and can be run economically under town conditions with the minimum of maintenance. This explains the increasing use of diesel engines, particularly in London, where nearly all taxis are now diesel powered.[4] In 1965 nearly half the taxis coming into use had automatic transmission. In addition to their longer life expectancy, this may reflect a growing awareness of the need to reduce driver fatigue, and we expect ergonomic factors increasingly to influence taxi design in future.

4.3 Effect of regulation on design

The London taxi is the best known example of a purpose-built cab. The specification was designed to meet the needs of the user

(1) For example, up to 30% in parts of the West End of London. See *Report of the Working Group on Piccadilly Circus*, HMSO, 1965.
(2) See *London Traffic Survey* (1962), vol. 1, Chapter 8, L.C.C. 1964, and *Economic Trends*, No. 116, June 1963
(3) See *London Traffic Survey* (1962), vol. 1, Chapter 8, L.C.C. 1964.
(4) Information supplied by the Public Carriage Office, Metropolitan Police.

and to ensure a high standard of safety. It is based on public service vehicle regulations, the effect of which is to add considerably to the cost. The original justification for some of the provisions may no longer exist, but in total the London-type taxi can meet most user needs. It has obvious advantages to the user over the saloon car type taxi – high doorways make for easy entry and exit; passengers have privacy and four can sit face to face, and the stowage of luggage is very easy. But it can perhaps be criticised for being too noisy, less comfortable than a car and inadequately heated in winter. In traffic the purpose-built taxi's manoeuvrability is an advantage. But if greater flexibility of size were allowed, operating costs might possibly be reduced, to the benefit of both operator and user.

4.4 The scope for limited purpose taxis

It is perhaps because the purpose-built cab meets so many needs, that little thought seems to have been given to the exact role of the taxi. The service it is called on to provide must be looked at against urban transport needs generally, to see whether the all-purpose cab, the modified saloon car, some other more specialised vehicle, or a combination of several types, can best meet these needs. It seems to us that two types of limited purpose taxi could make a contribution to urban transport needs in the future – a small taxi able to carry two passengers and a little luggage, and a taxi with room for more than four or five passengers which in some ways would be akin to a small luxury bus.

4.4.1 The scope for a small taxi

Average taxi passenger occupancy in London (excluding empty running) is 1·52 persons.[5] This suggests that taxis capable of carrying two passengers and a limited amount of luggage would be adequate for most passenger journeys. Such vehicles could be a good deal smaller than the present-day all-purpose taxi, and could be designed along the lines of a citycar to take advantage of any special road facilities of the sort discussed in Chapter 3. The scope for such a taxi would depend on the benefits it would bring to the user and the operator being sufficient to outweigh the disadvantages of its limited carrying capacity. Its attractiveness to the user would rest on cheaper fares and perhaps quicker journeys, while operators would benefit if lower fares increased demand for taxi services. But if small taxi running costs were only slightly less than those of the larger taxis that would still be needed for the journeys for which two-seaters were unsuitable, then the two-seater would make little impact. Different factors were no doubt at work, but in London eighty years ago there were some 7,000 two-seater hansom cabs and only 4,000 four-seater growlers.

4.4.2 The scope for a large taxi

Taxis with room for more than four or five passengers and with good luggage capacity would be a form of transport intermediate between the car and the bus. They would be particularly suitable for carrying people between rail and air termini and to and from major hotels, for distributing commuters from bus and train stations and perhaps for providing a door-to-door service from residential areas direct to central area destinations. They might operate on fixed routes, perhaps only at certain times of day or on a pre-booking basis. But even such services that operated on fixed routes only, would, we think, in terms of cost, scale of demand, and above all, comfort, performance and convenience, be more like an extension of a taxi service than of a bus service, although having some of the characteristics of both.[6] Again, the benefits to the user would be cheaper fares and, in some ways, a different sort of service from that to be got from all-purpose taxis; from the operator's point of view, there would be advantages in being able to offer a service that could attract custom from perhaps both public transport and the private car. No altogether suitable vehicle exists at present,

(5) *London Traffic Survey* (1962), vol. 1, Chapter 8. L.C.C. 1964.
(6) Limited capacity buses are also discussed in Chapter 5.

although the twelve-seater American 'Checkerbus' and the twelve-seater Bedford-'Martin Walter' coach represent different approaches to the problem. But there is no doubt that, given an effective demand for this sort of service and a realistic administrative framework, there would be no difficulty in designing a suitable vehicle.

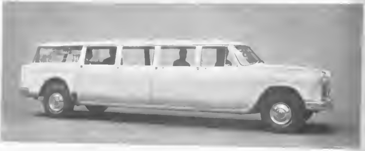


Plate 4-2A The 12-seater 'Checkerbus'

Plate 4-2B Bedford 'Martin Walter' 12-seat coach

4.5 The administrative framework

The present system for the control of taxis in this country has led to the use of two different types of vehicle – the purpose-built cab and the modified saloon car. Regulations tightly controlling design are a deterrent to the development of taxis of more imaginative design or for radically new roles, and it seems to us that if the benefits of better design are to be realised, the regulatory framework must take account of the total transport needs of an area. This would ensure that the taxi was able to make the best contribution to traffic needs and that advantage could be taken of any developments, whether initiated by the manufacturer or operator, that resulted in it being better able to do its job. This suggests that the licensing of taxis and the transport planning functions of a town should be in the same hands. The lack of such an integrated framework is particularly apparent in London where the regulation of taxi design and licensing is vested in the Home Office and the Metropolitan Police, and responsibility for traffic policy generally lies with the Greater London Council.

4.6 Conclusions

The taxi could, regulations permitting, be designed to carry anything up to a dozen people. In any town it is clearly both in competition with, and complementary to, public transport and the private car. The proper role of the taxi will vary from place to place, as will the best type or types of vehicle to be employed. But it is clear that the taxi is most likely to make the greatest possible contribution to urban transport if operators and manufacturers are free, within the overall framework of a town's needs, to provide the types of service for which there is a public demand.

Plate 4-3 'The development of taxis of more imaginative design' – New Russian taxi

5 Buses and coaches

In some ways, buses and coaches impinge on towns as other vehicles do – through noise, pollution, the space they take up, and accident risks. These problems and the possible ways of coping with them are discussed in other chapters; in this chapter we consider only those features of buses and coaches that relate specifically to the convenient and efficient movement of passengers.

5.1 Buses and town traffic

In 1954, more than half of all road travel was by bus or coach. In 1964 travel by bus and coach accounted for less than a quarter of all travel by road. Over the same period the cost of fares went up by 65%, as compared with an increase of less than 20% in the cost of running a motor vehicle, and an increase of about 30% in consumer expenditure as a whole.[1] Figure 5:1 reflects this travel trend and suggests how it may continue over the next twenty years. Nevertheless, except in London, buses and coaches still carry by far the greater proportion of all public transport passengers. There are fewer vehicles, but they offer much the same total seating capacity as they did ten years ago. They have largely replaced trolley-buses; and have almost entirely ousted the tram, contrary to the trend in much of Europe, where tramways have been maintained and improved, especially in the larger cities, so as to provide semi-rapid transit facilities operating on reserved and partially segregated tracks.

As figure 5·2 shows, the ratio of buses to cars in traffic ranges from only about one in 40 in a small town to about one in 8 in Leeds. In Central London, the ratio during the peaks is much the same as it is in Leeds. Collectively, buses therefore form a comparatively small part of total traffic. Individually, they are estimated to have between two and three times the congestion-forming potential of an ordinary car; but at peak travelling times each carries, on average, rather more than 20 times as many people as does a car and in the direction of the main tidal flow the proportion is much greater. Buses thus offer big advantages in making the best use of limited road space.

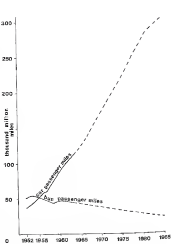


Figure 5:1 Total movement by bus and private car

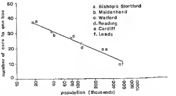


Figure 5:2 The ratio of cars to buses in the centres of towns (peak period traffic)

(1) See Ministry of Transport *Passenger Transport in Great Britain*, 1964. HMSO, 1965.

5.2 The future for buses in towns

The design of buses is inseparable from their roles These are undergoing re-appraisal and no clear pattern for the future has yet emerged. Overshadowing all bus operation is the effect of the growth of car ownership In the past, the job of public transport has mainly been to provide a service for those with no other means of transport and although bus operators are losing some types of traffic permanently to the private car, the need for buses will remain. In most large towns, road capacity is not likely to grow as fast as vehicle or car ownership, and a decreasing proportion of car owners is likely to be able to use cars for journeys to work in the town centre. So public transport, particularly buses, will have to attract an increasing proportion of car owners. Restrictions – through price or otherwise – on the use of cars could obviously make it relatively more attractive to travel by bus than by car. But a more positive approach is to design buses and promote a service that will be as attractive as possible to the customer. As compared with the private car, public transport has inherent disadvantages. For example, it can rarely, if ever, compete in convenience as a means of immediately available door-to-door travel. Nor can it offer the privacy and often the comfort of the private car. It is perhaps significant that in the type of service where the industry has gone out very strongly to attract traffic in the face of car ownership – the holiday coach tour – the changes in public service vehicle design have been most marked. We consider that big changes will be needed in the design of the ordinary stage-service bus if it is to make a more effective contribution to urban travel.

Plate 5-1 Changes in public service vehicle design have been most marked in the luxury coach

Any attempt to foresee the likely future role of buses has to take account of the trends in each part of the overall pattern of bus travel. The trend in Manchester[(2)] over the period 1950 to 1964 is significant. The total number of passengers carried fell by about 28%, but this decrease was not spread evenly over the week. There was a fall of about 25% in Monday to Friday traffic, as compared with about 36% on Saturdays and nearly 40% on Sundays. On weekdays the fall during the off-peak hours was greater than during the peak. The way in which weekend and off-peak traffic has fallen faster than weekday peak traffic is a pointer to the future role of buses.

Despite the uncertainties, there are some roles that buses seem likely to have to meet for as far ahead as can be foreseen.

(2) See *Motor Car and Motor Bus* by A. F. Neal. Paper presented to Public Transport Association. May 1965.

These are:

(a) *the peak hour journeys to and from work.*
Whatever increased use of cars might be brought about by the sort of possibilities discussed in Chapter 3, it seems to us that bus services will continue to be important means of peak hour travel because of their high utilisation of road space. For these journeys the bus will often have to attract the car-owner. The implications of this for the service to be provided and for vehicle design are discussed in Section 5.5.1 below.

(b) *services within a town centre.*
The characteristic of these is that individual journeys will be short and services will need to be frequent. We discuss this in Section 5.5.2 below.

(c) *off-peak services for those who cannot or do not want to use personal transport.*
Even with the sort of car ownership levels foreseen for 25 years' time, there will still be a good many households without cars. And within car-owning households, the young, the very old, the infirm and so on, will sometimes need to travel by bus. A third of the population will be unable to drive themselves They will continue to generate demands significant in total, but spread widely in time and space. We discuss this in Section 5.5.3 below.

Buses will, of course, have other uses. But it seems to us that these three tasks will influence the types of service and vehicle needed sufficiently to warrant considering them in some detail.

5.3 Characteristics of bus travel

The importance of various characteristics of bus travel obviously varies between different types of service; and the significance of these characteristics for vehicle design also varies widely. Some important aspects are:

(a) *Convenience* which includes end-to-end journey time, frequency, regularity and reliability of service, picking up and setting down points close to the true beginning and end of the passenger's journey; and facilities for carrying at least a certain amount of luggage or shopping.

(b) *Comfort* which includes providing enough seats for those who want them; good seat design and adequate spacing, good lighting; air conditioning; smooth acceleration and braking; good riding qualities; the minimum of internal noise and vibration; and ease of getting on and off.

(c) *Satisfaction.* Travel by bus is slow, as compared with surrounding traffic. This, and the lack of something to do, as compared with driving a car, contributes to making routine bus journeys seem tedious. It also makes bus travel seem less attractive than travel by other forms of public transport.

(d) *Size.* A large bus can cope with a wider range of numbers of passengers and is usually more economic than a small vehicle operated by the same crew. As against this, longer and wider buses become increasingly less manoeuvrable and difficult to fit into the general flow of traffic; and from the user's point of view may result in less frequent services.

(e) *Cost of fares* The car owner tends to compare bus fares not with the full cost of motoring but simply with the cost of petrol; in other words, he makes a rough assessment of the marginal cost of using his car.

5.4 Characteristics of bus operation

Two general and related considerations dominate the problems and possible design developments of the bus industry – labour costs and fare collection. A further, and increasingly important factor, in part related to fare collection, is the need for interchange facilities, both between private and public transport, and between one form of public transport and another.

Plate 5–2 'Good seat design and adequate spacing, good lighting; air conditioning'

5.4.1 Manning

Bus operation is labour intensive. Labour costs account for about 70% of all operating costs.(3) It is estimated that one-man operation of buses can reduce total costs by 15 to 20%, yet at present only about 8% of all stage service mileage is one-man operated.(4) Chronic labour shortage in the industry in many towns where bus services are particularly important, as well as increasing operating cost, emphasises the need for much greater use of one-man operation. We do not see this as one man doing two men's jobs but rather as the automation of fare collection and the rationalisation of passenger movement.

5.4.2 Fare collection

We have assumed that some system of fare collection will continue to be needed. For short distance town journeys there is a need to carry a higher proportion of standing passengers, so as to increase the capacity of buses at peak travelling times. The present British system of having a conductor who circulates among passengers collecting fares is particularly unsuited to this, quite apart from the question of one-man operation. Various arrangements – flat fare operation, prepurchase of tickets or tokens, season tickets, automatic ticket machines, payment on leaving the bus and other systems – can contribute towards solving the fare collection problem. They are potentially economic, in that they can eliminate the need for a conductor. All of them require that passengers should pass a checking or payment point of some kind when entering or leaving the bus. The implications for vehicle design can be seen by considering examples of such systems which, although not yet in general use in this country, may well be setting the pattern for the future. Examples are the token system used in Copenhagen and recently introduced in Sunderland, various other flat fare systems and the systems under development by London Transport for automated collection of stage fares.

The Copenhagen system combines single-deck high capacity (36 seated and 55 standing) buses with one-man operation, quick loading and unloading and a token or cash system of fare payment. The bus has two parallel entrances at the front: one is for token holders who, on entering the bus, change one or two prepurchased tokens for a single or double ticket, according to the length of journey they wish to make. Tokens can be bought in a variety of ways before boarding the bus. Passengers without tokens can buy tickets for cash from the driver on entering the bus, but at a higher price. Buying tokens in advance saves boarding time and so speeds up the bus schedule, provided the

Plate 5–3 The Copenhagen bus – one entrance for token holders and one for passengers buying tickets

(3) The following breakdown of costs is derived from an analysis made in the National Board for Prices and Incomes Report No. 16 on Pay and Conditions of Busmen (May 1966). Cmnd. 3012, HMSO, 1966.

	% of operating costs
Drivers ...	27
Conductors ...	22
Traffic and Administrative staff ...	7
Cleaning, maintenance and repairs (including labour) ...	15
Tyres ...	2
Fuel ...	11
Insurance, licences, operating and administrative overheads ...	10
Depreciation of vehicles ...	6
	100

(4) National Board for Prices and Incomes Report, No. 16.

incentive is sufficient to make ticket buyers the minority of passengers The exit is a double door in the centre of the nearside of the bus. The County Borough of Sunderland recently introduced a similar system The vehicle layout is shown in figure 5:3

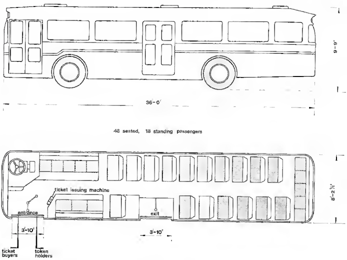


Figure 5:3 Layout of Sunderland's one-man operated single-deck bus

London Transport's recently introduced one-man operated 'Red Arrow' service provides a flat fare service, operating between Victoria and Marble Arch during the peak hours and over a longer route at other times of day. The flat sixpenny fare facilitates automatic fare collection. Front entrance doors lead to two turnstiles which automatically admit the passenger on payment of 6d. An automatic change-giving machine is installed alongside one of the turnstiles for those who board without small change.

Plate 5-4 Sunderland's high-capacity one-man operated bus

Figure 5:4 shows the layout of the bus, which is similar to the Copenhagen and Sunderland vehicles, except for the turnstile passimeter and the higher ratio of standing to seated passenger accommodation.

The layout and passenger circulation arrangements in these buses are suitable for a flat or simple zonal fare, and for services where it is acceptable to have a significant proportion of standing passengers. For the longer distance town services, seats for all may be needed, with a fare collection system that enables a range of fares to be charged. (We are not competent to discuss the economics of flat and zonal fare systems over large areas, but we note that flat fares, after having been widely adopted in North America, are now being replaced by graduated fare systems.) A system of combining a mileage fare with automated collection would involve having an entrance near the centre or rear of the bus, with passengers obtaining, for example, a magnetically printed ticket on entry and having to pass an exit turnstile which would read the ticket and calculate the fare. Boarding time would be saved and the collection of fares would be spread out along the route. As the check point would be at the exit, this would have to be at the front of a bus if the bus were to be one-man operated.

Plate 5-5 The ticket-issuing machine on Sunderland's buses

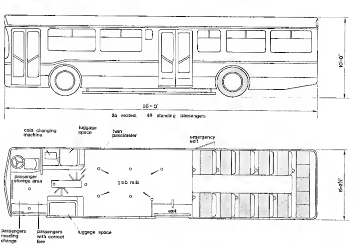


Figure 5:4 Layout of London Transport's 'Red Arrow' single-deck bus

Plate 5–6 London Transport's 'Red Arrow'

Plate 5–7 The twin 'passimeter' on the 'Red Arrow'

5.4.3 Interchange

The facility for passengers to transfer from one bus service to another, and between buses and other forms of transport, public or private, also affects bus design. This aspect of bus operation is likely to become increasingly important in the context of a properly integrated urban transport system aimed at making the best use of the facilities offered by various means of travel.

A public transport service aiming to compete with the private car must extend deeply and widely into the areas it serves, so as to provide bus stops as near as possible to the passenger's true starting point and final destination. For some journeys this can be done by providing through bus services, without expecting passengers to change from one route to another. For other journeys – and perhaps the majority of the longer journeys in towns – it means that at one or more places en route the passenger will need to change, from bus to bus (perhaps with different operators), rail to bus, car to bus, or from coach to taxi. All these possibilities (and their opposites when travelling in the reverse direction) have very wide implications, involving for example route-ing, integrated fare structures and inter-validity of tickets, as well as the design of railway and bus stations, car parks and bus stops. We have considered these implications only in so far as they affect the design of the bus itself.

Essentially, it must be possible to make the transfer with the minimum of delay and, in our climate, preferably under cover. One of the great attractions of the private car is that it offers dry, warm, comfortable through travel, independent of the weather. In contrast, because of the primitive interchange arrangements now commonly found in towns, public transport users must be prepared to carry their own protection against wet and cold, even though the buses themselves may be fully air conditioned.

Buses designed for easy interchange need high capacity entrances with, perhaps, exits on both sides of the bus, a feature which would also be an advantage in one-way streets. This means having power-operated doors under control of the driver. It could also lead to the driving position being in the centre rather than on the offside. Because of the virtual impossibility of having raised platforms at all bus stops, the entrance and exit steps must be as easy to negotiate as possible from kerb level. This implies a low floor, which has important consequences for the design of the chassis and in particular tyres and wheels, brakes, suspension, and the location of the engine and the transmission. Weather protection during interchange means covered transfer areas. With entrances and exits on the near-side only, this could entail roofing (or subways) between 'platforms'. Roofs would need to be very high for double-deckers to pass under them, and subways are expensive and not always possible. But, with doors on both sides of the bus, canopies and screens over the platforms themselves might be enough. A further factor would be the effect of inter-validity of tickets on the system of fare collection and, hence, on the design of the bus itself. All this points to the need for radical thinking on the whole question of interchange facilities generally, and their effect on bus design and operation in particular.

Plate 5–8 Poor interchange facilities

Plate 5–9 Good interchange facilities

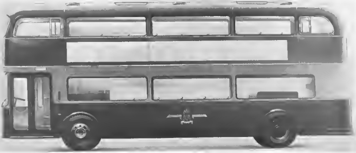
5.5 Design needs for some particular types of service

In the light of the general considerations already set out, we have looked at the sort of bus design features that would be appropriate to the particular sorts of service set out in Section 5 2 above

5.5.1 Peak hour services

As we explained in Section 5.1, peak hour services will continue to be vital in existing large towns We have also pointed out that buses cannot hope to compete on equal terms with the private car. But travellers will expect to be able to make their journeys as quickly as possible. Boarding and alighting time (and hence fare collection arrangements), acceleration and braking and, perhaps, top speed capability all contribute to this, and need to be taken account of in design.

Plate 5–10 An example of a modern double-deck bus



With the traditional combined entrance and exit no one can board the bus until all, or nearly all those wishing to alight have done so. Even so, in present-day stage service bus operation, the average boarding time is about $1\frac{1}{2}$ seconds and alighting time is about 1 second per passenger. Fare collection by a roving conductor does not usually affect boarding and alighting time. Separate entrances and exits prevent the sort of delays caused by combining them. If one-man operation is also introduced the limiting factor tends to be the method of fare collection; but with an efficient system, and a well-designed vehicle, loading and unloading need take no more time than with the traditional open-platform bus, and may even take less. Separate entrances and exits may slightly reduce seating capacity, but need not necessarily reduce overall capacity, because the one-way movement of passengers through the bus allows more standing passengers to be carried without obstructing entry and exit. Separate entrances and exits do, however, add significantly to the cost of construction and maintenance.

The maximum acceleration of buses is not much more than 1 mph per second and is less for some double-deck buses. The effect of this on traffic congestion (compared with maximum accelerations of about 4 to 5 mph per second commonly available, and 3 to 4 mph per second commonly used, in cars) is discussed in Chapter 2. Here we are concerned only with the effect on bus services. Car-like acceleration would be undesirable in a bus with passengers continually moving to and from the entrances and exits. But London Transport trains use up to 2 mph per second and this suggests that a level of 2 to 3 mph per second on buses would be acceptable provided that the rate of change of acceleration was not greater than about 2·2 mph per second per second. This degree of smoothness cannot reliably be achieved with manual gear change but should be possible with automatic transmission. Figure 2·5 in Chapter 2 shows the effect on journey time of improved acceleration. An improvement from 1 to 2 mph per second could save nearly four minutes, or about 15% of journey time, on a typical five-mile-town bus journey with five stops per mile. And a further improvement to 3 mph per second, which is probably the acceptable maximum for standing passengers' safety and comfort, could save over five minutes, or more than 20% of journey time, in all. Time saved by passengers would not be the only advantage. It might also be possible to provide either the same service frequency with fewer buses or a better frequency with the same number of buses. Although higher accelerations would increase the first cost of a bus and perhaps also its running cost, we are advised that a 10% saving in journey time could well pay for itself by reducing total operating costs.

Decelerations of up to 3 mph per second are already common in service conditions and this is as high as passenger comfort allows.

The top speed of buses in town is adequate for town conditions, and higher top speeds would be easily attainable if they were justified.

Better acceleration and higher running speeds would accentuate the need for smooth riding qualities. In this, the double-deck bus has disadvantages. Passengers on the stairways are particularly vulnerable to bus movement, and roll and pitch are always accentuated on the upper deck. These reasons, as well as the problems of supervision in one-man operation of double-deckers, suggest that the single-deck bus may be an increasingly more suitable type of vehicle for town use. They also probably rule out the idea of a three-deck vehicle, quite apart from loading and unloading, stability and route-ing problems. We do not, however, suggest that the double-decker will not have a continuing role, especially for heavily loaded routes running into town centres. It can always offer a higher seating capacity – though not necessarily higher total capacity – than a single-decker of the same length, width and manoeuvrability; and it seems to us to be at least questionable whether its greater height is as much of an intrusion on the urban scene as is sometimes suggested.

Greater comfort in buses is not, technically, difficult to provide. More sophisticated suspension systems, individual seats, sound-proofing, air conditioning and good lighting have all been applied in coaches and show the standards of comfort that are possible, at a price.

5.5.2 Town centre services

Bus services within town centres are at present provided chiefly as parts of radial or through routes. This limits both the quality of service and the prospect of using a specially-designed vehicle. Services in town centres are needed to distribute passengers coming in by road or rail on longer distance services; to distribute passengers arriving at car parks on the perimeter of the central area; and to provide links between shops, offices and the like within the central area. These needs point to a small, manoeuvrable vehicle able to make full use of the central area street network; quick and easy boarding and alighting, particularly at interchange points; a comparatively high proportion of standing passengers, because journeys will be short; and automated flat-rate fare collection, for simplicity and economy.

Washington D.C. has a bus service of this sort[5] and the London Transport 'Red Arrow' bus is providing an off-peak service with some of these characteristics but using a relatively large, high capacity vehicle designed primarily for peak hour operations. The apparent success of the peak hour 'Red Arrow' service itself suggests that, despite their lack of manoeuvrability compared with the bulk of the traffic on town roads, very high capacity buses, perhaps capable of carrying upwards of 100 passengers, many of them standing, may have a place in providing the short-distance links between termini and central area destinations.

5.5.3 Other services

Other services differ from the peak and town centre services because, basically, they are not in such direct competition with the private car. The main user of these services seems likely to be someone without a car – often the poor, the young, the old, and the infirm. These types of user will need a service which must above all be cheap but which is unlikely to be intensively used. They will also need some luggage space. This suggests that services of this type may offer a means of using the residual life of still serviceable buses that cease to meet the needs of more competitive and demanding routes. But the community may demand something better than this, even at the expense of some special financial arrangement.

[5] The Washington minibus service started as an experiment in 1963. During the trial period the buses carried about 6,000 passengers a day, and their popularity enabled the service to continue on a commercial basis. A fleet of 10 buses each 20 ft long and 7 ft 6 in wide, and capable of carrying 30 passengers (18 seated, 12 standing) provides a $2\frac{1}{2}$ minute service over a $1\frac{1}{2}$ mile route in the central business and shopping district of Washington D.C. The buses are one-man operated and a low, flat fare is charged. The effect of the service has been to stimulate trade and to reduce traffic along the route by 4% through less use of cars and taxis. About 1,500 people per day who previously walked along the minibus route now use the service. See *The Minibus in Washington D.C.* Mass Transportation Demonstration Project. Final Report, 1965.

Plate 5–11 The Washington minibus

Plate 5–12 An 'executive' coach

5.6 Conclusions

We are of the opinion that future operating needs are not likely to be met, as in the past, by a general-purpose bus. This does not necessarily mean a wide range of different types of vehicle. The needs of a particular undertaking might well be met by two or three types. But the standard and versatility of service implied raises design problems of some difficulty – perhaps the biggest two being automating fare collection without going over to flat rates, and the achievement of much better accelerations without incurring excessive engine and transmission costs or prejudicing wear life and mechanical reliability. These pose significant technical problems, but in our view they are certainly capable of solution well within the time-span we are considering.

There is also the problem of optimum size. A high capacity bus offers operating economy. But buses built to the present maximum dimensions – 36 ft 1 in long (and there are proposals to extend this to 39 ft 4½ in), 8 ft 2½ in wide, and with a maximum swept turning circle of 71 ft – are larger than all other normal road vehicles except heavy goods lorries which, themselves, make up a comparatively small part of urban traffic and are not so tied to routes and timekeeping. Large buses need wide traffic lanes and plenty of room to negotiate the sharp turnings found in most existing town centres. A substantially narrower and shorter bus would not only be more manoeuvrable; it could increase the possibility of obtaining an extra traffic lane on existing streets, perhaps reserved for buses at certain times. We suggest it could be well worthwhile making a design study on optimum bus size for town centre use, taking all the operating traffic and economic factors into account.

But the main factors inhibiting some of the foreseeable development are not at present technical but financial and organisational. In this country the stage bus has, for years, been losing custom to other forms of travel. Unless some change in incentives is imposed as a matter of policy, the growth of car ownership can be expected to continue to erode the viability and hence the competitiveness and, perhaps, the efficiency of bus operation. Without taking any view on the merits of various means of adjusting the balance of competitiveness between private and public transport, it is nevertheless clear that under congested town conditions, some road users are not now required to face the social costs they impose on others. The practical effect of this is to leave car users, who average about 3 to every 2 cars – and even less at peak travelling times – adding greatly to congestion and paying less – in economic terms – than the real cost of using congested roads, as compared with bus passengers who number from 20 to perhaps 70 or more per bus at peak times. This, and other pressures, have forced operators to give undue weight to keeping down fares. This has resulted in a service that tends to fall short of the needs of the community and becomes increasingly less competitive with other means of travel. We are neither competent, nor is it our job to suggest how any new financial framework can best be provided. But it seems unlikely that the full benefits from what is technically possible in the design of buses and coaches will be achieved so long as operators are expected to operate under conditions in which fares sometimes hardly cover costs, and in which fare increases encourage more people to switch to private transport – which although cheaper to them personally is often more expensive to the community as a whole.

6 Goods vehicles

Goods vehicles range from small delivery vans to large articulated lorries. In this chapter we look at the size and composition of the goods vehicle fleet, and in the light of the overriding need to keep traffic congestion to a minimum, consider the extent to which design considerations, such as vehicle dimensions, power and facilities for loading and unloading, influence and are influenced by operating patterns.

Many things – such as the national income level, the regulatory framework, changing manufacturing, wholesaling and retailing techniques and methods of storage, and restrictions on the use of roads for loading and unloading – affect the movement of goods by road. Above all the future role of the goods vehicle will depend on the place of road haulage in relation to the railways and coastal shipping.[1]

6.1 Present trends

At present, road transport carries the bulk of goods in this country, moving some four-fifths of the total tonnage and over half of the total ton-mileage. These figures reflect the greater average journey lengths by rail (about 70 miles) than by road (about 25 miles). Many short journeys are necessarily made by road, while delivery is often made by road from rail terminals. The relative importance of road haulage, the railways and coastal shipping is perhaps best reflected by their respective shares of all hauls of more than 100 miles – in terms of ton-mileage the breakdown[2] is roughly, road haulage 40%, railways 30%, coastal shipping 30%. This suggests that each has an important part to play.

In central London, goods vehicles of all kinds form just over a third of all traffic.[3] Figures 6:1 and 6:2 show the purposes for which they are used in the survey area as a whole[4] and the pattern of journeys in terms of the destinations served. Most of the journeys to people's homes are retail deliveries, mainly by milk floats. Retail delivery journeys are almost invariably made by day, commonly beginning in a town centre. Nevertheless, it seems that wholesale deliveries, of which over two-thirds are to shops, and five-sixths are carried out between 8 am and 5 pm, are the main source of the traffic congestion caused by goods vehicles in town centres.

(1) The apparent trend towards the increasing use of road transport at the expense of the railways masks a complex situation with which the Geddes Report on *Carriers' Licensing*, HMSO, 1965, dealt fully. The Geddes Committee concluded that there was little direct transfer from rail to road, but that there was a disparity in growth between the trades and industries for which road transport is specially suitable and the industries for which rail has special advantages.

(2) Geddes Report, para. 3.13.

(3) See *London Traffic Survey* (1962), Vol. 1, Chapter 8. L.C.C. 1964.

(4) An area rather larger than Greater London. See *London Traffic Survey* (1962), Vol. 1. L.C.C. 1964.

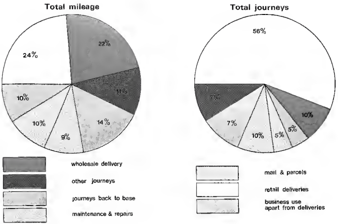


Figure 6:1 The purposes for which goods vehicles are used in the London area

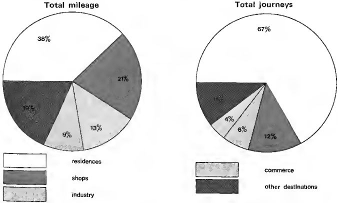


Figure 6:2 Destinations served by goods vehicles in the London area

Figure 6.3 shows two significant trends – the number of goods vehicles is growing, and larger vehicles are forming an increasing proportion of the total goods fleet. Although the medium and heavy goods vehicles together represent under a quarter of the total fleet, they tend to move larger loads over longer distances and carry the bulk of all goods moved by road.

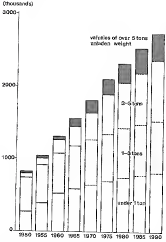


Figure 6:3 Number of goods vehicles licensed in this country. Actual 1950–1965. Forecast 1970–1990

Innumerable variations in operating patterns exist, but broadly two types of goods vehicle journey predominate – long hauls which may or may not involve either picking up or delivering goods in town centres, and urban distributive services. Goods vehicles in towns therefore span the full range from light distributive vehicles which rarely, if ever, leave a narrow operating area, to heavy vehicles primarily intended for long hauls. Operating patterns tend to vary according to the category of licence holder,(5) so it is significant that the proportion of the goods fleet run under C licence has been steadily increasing, and now accounts for nearly nine-tenths of the total fleet. However, there is no indication that the licensing system has any influence on vehicle design.

The maximum size and weight of goods vehicles is controlled by Construction and Use Regulations.(6) Figure 6.4 shows the extent to which successive increases in the maximum permitted dimensions have allowed larger and heavier vehicles, and in the foreseeable future we can expect vehicles of up to 50 to 60 feet in length to be used in this country. The 1964 amendments show how the regulatory framework can affect design by influencing the relative costs of using different types of vehicle. Before 1964 rigid vehicles were generally most economic for long hauls, but with the change in the permitted maximum operating limit to 32 tons, and the raising of the limit for rigid eight-wheel vehicles to only 26 tons, articulated vehicles became most economic for such journeys, for only they could make full use of the maximum permitted all up weight. Changes in Construction and Use Regulations in the future might well alter further the existing economic balance, for example, the attractiveness of larger vehicles would increase if the regulations were to allow them to carry very large containers of the type now being used internationally.

6.2 Engineering design possibilities

The operator aims to get the best possible return from his vehicles. This means that they should be reliable, carry the maximum possible load for their size, be able to get as close as possible to their destination, and be easy to load and unload. The delivery of goods is a labour intensive operation, and the pressure of costs is such that the operator is continually looking for ways of improving efficiency. In consequence, more and more vehicles are being 'purpose-built' to the individual operator's needs, and this trend towards the greater use of special purpose bodies and supplementary equipment can be expected to continue.

6.2.1 Manoeuvrability

In practice, design changes to improve manoeuvrability tend to be offset by the use of longer less manoeuvrable vehicles. Any marked improvement in vehicle manoeuvrability in the future will therefore depend not only on the free development of design, but also on regulations specifying maximum swept turning circles. Alternatively, it may be necessary to limit the size of vehicles entering town centres or restrict them to certain routes.

6.2.2 Transmission and suspension

Automatic transmission is being increasingly used in light goods vehicles, and is to be found also in a few medium sized vehicles. Although its advantages may be slight on long journeys where there are comparatively few gear changes and where fuel consumption may be adversely affected, its advantages for vehicles which are driven in congested urban areas or by several different drivers are being more widely appreciated, and we expect its use to increase. We also expect the trend towards the use of better suspension systems to continue. Leaf springing has disadvantages in that it contributes to noise, especially in unladen vehicles, while maintenance is difficult and costly; if automatic lubrication is used, oil can be spilled on the road. Coil-spring, rubber and air suspension systems(7) do not have these disadvantages and their increasing use will therefore benefit both the operator and the general public.

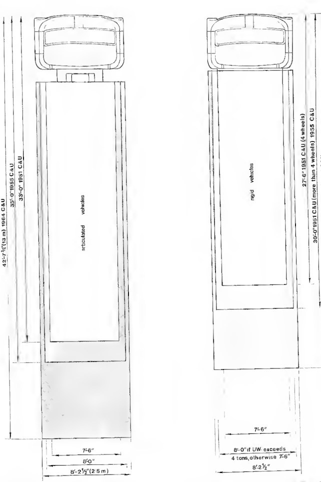
6.2.3 Ergonomic factors

Greater attention is being given to ergonomic factors in the design of goods vehicles, and power operated or power assisted steering and brakes are becoming increasingly common on the heavier vehicles. More regard is being paid to the design of the driver's cab to improve access, visibility, safety, comfort, ventilation and ease of control. We expect this trend to continue with particular emphasis being placed on improvements in vehicles for town use, for example, by greater use of sliding doors and roller shutters to improve access to the cab and vehicle interior and labour saving loading and unloading devices.

(5) 'A' and 'B' licences are held by hauliers carrying other people's goods for reward. 'C' licensed vehicles are run solely in the interests of the operator's own business. The licensing system is fully discussed in the Geddes Report

(6) See glossary.

(7) See glossary.



Note
Lengths shown do not apply to articulated vehicles constructed and used for the carriage of very long indivisible loads.

Figure 6:4 Changes in the maximum dimensions of goods vehicles

Plate 6–1 'Ergonomic' cab

Plate 6–3 Side loading

6.2.4 Bodywork

Goods vehicle bodywork is becoming not only more specialised, more complicated and more expensive, but also more soundly engineered and more closely related to the job to be done. It can contribute greatly to the ease with which a vehicle can be loaded and unloaded. Means of reducing the time and effort of loading and unloading include 'walk through' cabs, pallet loading, demountable bodies, power operated tail loaders, conveyors, moving floors, built-in cranes, and interchangeable containers. These developments provide considerable scope for more mechanisation.

Plate 6–2 Demountable body

Plate 6–4 Conveyor loading

6.2.5 Articulated vehicles and trailers

Broadly, there are two main types of operating pattern with which articulated vehicles are associated High utilisation of small and medium sized articulated vehicles used for distributive services in towns is achieved through semi-automatic or fully automatic coupling and uncoupling, the prime mover leaving one semi-trailer to be loaded or unloaded while it moves another one In contrast, large long-haul prime movers and semi-trailers often remain more or less permanently coupled. Articulated vehicles are often better than rigid vehicles from the traffic point of view and are generally much more manoevrable than rigid vehicles with trailers. Articulated vehicles offer greater operating flexibility and a higher load potential than rigid vehicles and lower operating costs than vehicles drawing separate trailers.

Plate 6–5 Long-haul articulated vehicle

Plate 6–6 Small articulated vehicle

Complete interchangeability between the prime movers and semi-trailers of an operator's fleet is essential for vehicles engaged on short hauls if they are to be used to best advantage. This means that coupling, braking and electrical systems must be standardised so that the two parts of the vehicle will always match. For vehicles engaged on long hauls the crucial things are the maximum pay load that can be carried and the relative costs of operating articulated vehicles, rigid vehicles and rigid vehicles and trailers, factors which are determined more by regulation than vehicle design. In recent years there has been a considerable advance in the detailed design of semi-trailers but there is still scope for further improvement in, for example, stability, braking, suspension and the design of couplings and headboards. Less progress has been made with separate trailers, mainly because their use has declined as they are restricted in size and weight, uneconomic and unwieldy in traffic. But we see no special problems in improving their design to meet any new demands.

6.2.6 Vehicle performance

Goods vehicle performance will become increasingly important as the trend towards bigger loads and increasing traffic congestion continues. This means not only better acceleration through improved power to weight ratios, but also better braking. The operator will only demand added speed if it allows him to complete an additional delivery or a return journey which would not otherwise be possible. However, better power to weight ratios will be needed to keep the congestion caused by goods vehicles to a minimum. Many medium and heavy British goods vehicles have a power to weight ratio of less than 6 bhp per ton. It is clearly impracticable to give them car-like acceleration and hill climbing ability, but adequate performance is essential and it may be necessary to prescribe by regulation either minimum power to weight ratios or performance standards. Possible developments in power units are discussed in Chapter 10, but it is clear that there would be few design difficulties in producing more powerful engines with better power to weight ratios, and that 6 bhp per ton could be met without difficulty. However, we are not in a position to say whether this or some higher standard would be necessary.

At present, operators generally are more interested in keeping maintenance and fuel costs to a minimum than in improved performance. This emphasis on economy has led to the increasing use of diesel engines. The vast majority of medium and heavy goods vehicles are now powered by diesel engines, and their use in smaller goods vehicles, which is becoming apparent, can be expected to become more marked in the future.

Increases in the size and weight and improved performance of goods vehicles will accentuate the need for improved braking. The principal difficulty may well be the provision of wheel brakes capable of dissipating the heat generated during braking. This suggests that some form of independent auxiliary brake such as an hydraulic or electric retarder[8] might become increasingly necessary on heavy goods vehicles to leave the wheel brakes cool for low-speed braking and emergency use.

Plate 6–7 The goods vehicle is a source of congestion (particularly in towns)

[8] See glossary.

6.3 Segregation

The goods vehicle is a source of congestion (particularly in towns) because of its size, its poor manoeuvrability, which increases the obstruction it causes when turning or moving in and out of loading spaces, and its lack of acceleration, which greatly reduces traffic flow especially in stop and start conditions. But on the other hand, the goods vehicle is an essential user of town roads and will clearly remain so. However, the growing number of lorries and the general pressure on road space in towns increases the need for keeping the congestion they cause to a minimum.

Plate 6–8 The difficulties of on-street loading by day

Regulation can help; for example, by restricting the entry of the largest and least manoeuvrable goods vehicles into town centres and by applying general street loading and unloading restrictions during much of the working day. More extensive restrictions, both in time and area, including more urban clearways (involving peak hour loading and unloading restrictions) seem inevitable. But such regulations by themselves are not the complete answer. For the operator, they interfere with his job of collecting and delivering goods, and both while moving and stationary goods vehicles would still cause some interference to traffic flow.

This points to the advantages for both the operator and the community as a whole of some segregation of goods vehicles from other traffic either in space or time. The former means the use of off-street loading and unloading facilities and the latter, special times for delivery in town centres, for example at night.

6.3.1 Segregation in space

The use of off-street loading and unloading facilities wherever possible has considerable design implications, for goods vehicles will increasingly be designed to make the best use of these facilities. This will lead to them becoming more and more 'purpose built' for the job to be done. Moreover, off-street facilities will need to be constructed to take full advantage of the special features of the vehicle. Apart from the provision of electric power to work a vehicle's mechanical handling equipment, bays and ramps can be specially designed for the vehicles using them. Above all, it is clear that the most efficient working pattern will only be established if the 'package' nature of the relationship between vehicle and premises is fully appreciated both in new building construction and vehicle design.

6.3.2 Segregation in time

In practice, segregation in time will usually mean goods delivery at night. This is already being tried by some firms which need to deliver to premises in the busiest town streets where access is very difficult by day. At present, night work tends to be unpopular and retailers and others receiving goods at night have to make special arrangements for their premises to be opened and for consignments to be checked. This means that many people besides the delivery driver are called upon to work night hours. But the increasing use of mechanical handling techniques and premises adapted to night delivery will greatly improve the position. Recent developments such as power-operated tail loaders, conveyors and moving floors make one-man loading and unloading operations practicable, whilst the use of sealed container delivery to say, a retailer's 'night safe', would obviate the need for staff to receive consignments. Such techniques would allow the most productive use of labour by both the retailer and the vehicle operator, and from the latter's point of view would allow the most intensive use of high cost capital equipment, for the vehicles could probably be used in non-congested areas by day.

This suggests that night delivery will be seen increasingly to be in the best interests of operators, retailers and the community at large. We therefore expect its use as a means of avoiding day-time congestion to spread, particularly where off-street loading and unloading facilities are not available.

This would have two main design implications for the goods vehicle. Firstly, design would increasingly reflect the demand for the aids to loading and unloading which make for efficient

Plate 6–9 The comparative ease of unloading in the late evening

night delivery Secondly, extensive night delivery would make vehicle noise a critical factor We suggest in Chapter 8 that the large commercial vehicle presents one of the most difficult problems from the point of view of reducing engine noise to acceptable levels Electric traction has worthwhile advantages in this respect, but as explained in Chapter 10, it also has important limitations which suggest that conventional storage batteries would not be a suitable power source for the majority of goods vehicles. But the zinc-air battery might overcome the disadvantages of existing storage batteries. However, not only will engine noise have to be kept within acceptable limits but noise from goods handling will also be important. We have shown that we expect more and more goods vehicles to be equipped with power operated handling equipment. At present such equipment is usually run from the vehicle engine but this may prove to be unacceptably noisy for night working in which case it would need to be driven electrically either from the vehicle's batteries or from an electric source at the premises where the delivery was being made. Even with across-the-pavement unloading, it should be possible to provide power points to which a lorry or van could be connected. But most power-operated equipment could, if need be, be electrically operated from the vehicle's own battery.

6.4 Segregation, operating patterns and design

Besides the design implications of segregation which have already been mentioned, segregation will influence goods vehicle design indirectly by stimulating operating patterns which in turn affect design Of these, the most important are likely to be the increasing use of interchange points and containers.

6.4.1 Interchange

Out of town interchange points, i e. depots at which consignments for town centres are sorted and co-ordinated so that the minimum amount of time is actually spent in congested areas, are already used by some road hauliers. We expect their attractiveness to increase as motorways and improved trunk roads stimulate the use of the largest permissible vehicles for the movement of bulk loads by road, and containers become more widely used, while on the other hand traffic conditions make it increasingly necessary to discourage the entry of such vehicles into towns. Great impetus will be given to the movement of goods direct to and from the Continent by road when the Channel Tunnel is constructed and this will make the problem even more acute. Even if interchange systems do not become essential to cope with the increasing use of the largest containers, the advantages to the community which interchange would give in terms of improved traffic movement and urban amenity might outweigh the disadvantages of extra handling and administrative costs, and these factors would need to be carefully evaluated.

6.4.2 The use of containers

The increasing use of containers (of an agreed standard range of sizes) for the movement of goods, both in this country and abroad, is particularly important. Broadly, these are of two main

Plate 6–10 Interchange depot

Plate 6–11 Special facilities for container handling

types – very large containers which are used for long distance hauls and international traffic, and smaller containers which make for easy handling to small outlet points such as retailers' premises. Both types of container greatly reduce handling costs and allow the most effective use to be made of expensive capital equipment, and the smaller containers have the additional advantage that they help to reduce traffic congestion in towns by, on the one hand, greatly improving the efficiency of night delivery and on the other, reducing the time needed for across the pavement deliveries when these are unavoidable. We therefore expect greater use of such containers in the future, and that vehicles will become increasingly fitted for handling them quickly.

The entry of the very large vehicles needed for the largest containers into towns creates problems, but if such vehicles were kept outside towns altogether, it might be possible to tolerate from them, for example, rather higher noise levels and poorer manoeuvrability. But some of them would still need access to towns, for example, to deliver to docks, and in such circumstances partial segregation by regulation would be necessary, i.e. special routes and times of use would need to be laid down. The use of two semi-trailers either in tandem or bolted together to form a single rigid body would help to overcome the need for big goods vehicles to enter towns. 'Doubles', as they are called, are already widely used in the USA. The combined unit is used for long hauls, but the semi-trailers are separated and each is hauled by a smaller prime mover for urban deliveries. At present, the Construction and Use Regulations do not permit an articulated vehicle to tow a trailer. This precludes the use of semi-trailers in tandem, but there is no reason why single rigid body tandems should not be used, and we expect them to become increasingly popular with operators in this country.

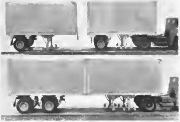


Plate 6–12 The Crane-Fruehauf twin-tainer – two vans in one

6.5 Conclusions

The need for and the possible ways of segregating goods vehicles from other traffic is likely to be the major influence on the design of such vehicles in our time scale. We have shown how closely possible design developments and operating patterns are related, and how, with the overriding need to reduce town traffic congestion, this relationship is the point at which the interests of the individual operator and the community as a whole meet and can conflict. We have indicated some of the design changes that can help to reduce this conflict. But above all, it is clear that a more deliberate balance than in the past will have to be struck between these interests.

7 Safety

7.1 Road accidents in towns

Traffic accidents in built-up areas[1] account for nearly three-quarters of all road casualties. These accidents happen at lower speeds than on the open road, and tend to be less serious. Even so, about a quarter of the 280,000 road casualties in towns in 1964 involved deaths or serious injury[2]. Thirteen out of fourteen pedestrian casualties occur in towns.

Accidents happen for many reasons. The behaviour of drivers and pedestrians, the design and state of the roads and conflicts between different road uses are important factors. Our particular concern is the contribution that vehicle design can make to road safety.

We have taken it as axiomatic that vehicles can and should be engineered so as to be mechanically safe, in the sense that provided they are properly maintained, accidents should not be caused by mechanical failure or malfunction. We have limited ourselves to considering:

(a) design features which make it less likely that an accident will occur; and

(b) the ways in which design can reduce the risk of injury both to vehicle occupants and to other road users if an accident happens.

7.2 Avoiding accidents

7.2.1 Control of the vehicle

A vehicle which handles well is easier and less tiring to drive, and contributes to the driver's ability to deal with the unexpected.

Well designed controls and good responsiveness to them are also important. Traditionally the controls have been arranged so as to divide the functions between the driver's hands and feet. But other arrangements have been tried experimentally, for example,

Plate 7–1 Ford's 'Wrist-twist' steering control

a single lever has been used to control turning, acceleration, braking, gear selection and the horn; wrist-operated controls have been substituted for the steering wheel; and pressure pads for pedals. Although new types of control might reduce the amount of elbow or leg room needed by the driver, there is little evidence to suggest that any of these systems would necessarily give better control or offer worthwhile advantages over, for example, the steering wheel. All of them involve a degree of complexity which could create new problems of reliability; and, there is the additional point that universality of controls is an aid to safety.

7.2.2 Loss of control

The greatest risk of loss of control is through wheel-lock and skidding. This can happen even on a dry road, but is much more likely on wet slippery roads. Town roads often become polished by a constant flow of traffic and are particularly dangerous when wet. The importance of good resistance to skidding is shown by the number of skidding accidents in wet weather – there were nearly 18,000 in built-up areas in 1964.[3]

Road surfacing is the subject of continual research and development to improve safety, and in recent years improvements in the design and manufacture of car tyres have also made a major contribution to better road-holding. Further development work on tyres can be expected to lead to continued improvement and to the improved car tyre construction techniques being increasingly applied to commercial vehicle tyres. But the problem of wheel-lock is bound up with the design of braking systems. These could be improved to reduce the risk of wheel-lock by devices such as those relying on load-sensing,[4] which already exist but need further development. More elaborate anti-wheel-locking devices, such as those found on aircraft, are costly and not yet generally suitable for use on mass-produced road vehicles. They are, however, being fitted to some high performance cars and a few heavy lorries. These devices not only prevent wheel-lock, but also reduce stopping distances on wet roads. The advantages they offer would be particularly great for motor cycles and mopeds, which are especially vulnerable to skidding

[1] That is, where speed limits of 30 or 40 mph apply.
[2] Ministry of Transport, *Road Accidents* 1964 HMSO, 1965.
[3] Ministry of Transport, *Road Accidents* 1964 HMSO, 1965.
[4] Load sensing devices vary automatically the braking effort applied to the vehicle's wheels according to the load they are carrying.

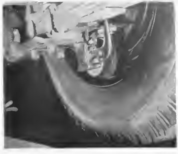


Plate 7–2 Dunlop Maxaret braking device

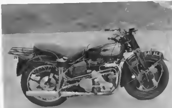


Plate 7–3 Anti-lock braking device on front wheel of motor cycle

7.2.3 All-round visibility

Good all-round visibility is exceedingly important to safety and depends largely on good design for the elimination of blind spots and internal reflections.

A good rear view is particularly important in towns, where vehicles are continually overtaking and changing lanes. This presents particular problems for buses and heavy goods vehicles, for which more sophisticated devices than ordinary rear view mirrors may be justified. Long periscopic or small closed circuit television viewers are possibilities, and their costs may become low enough for them to be installed on the more expensive and intensively used vehicles.

Keeping the windscreen and other glass clear, both inside and out, remains a problem. But new solutions may be possible. For example, internal misting might be largely overcome by double glazing; and recent developments in the manufacture of safety glass may make this more feasible than has been possible hitherto.

7.2.4 Lighting, signalling and warning equipment

Quite apart from the illumination provided by the headlamps, vehicle lighting serves to indicate the vehicle's presence and is used as a means of signalling. Better street lighting is already being provided on main traffic routes in towns, and we consider that greater safety at night is more likely to be achieved by this means than by improving the performance of vehicle headlamps. The use of a vehicle's lights to indicate its presence is another matter. Experiments are in progress to determine the value of, for example, using headlights to distinguish between stationary and moving vehicles at night and in bad visibility, both in built-up areas and elsewhere. We see nothing technically difficult in this.

At present, vehicle signalling equipment can show when a vehicle is about to move off or turn, and that the brakes are being applied. As town traffic becomes more dense, signalling systems may be needed which give better information about a vehicle's intended behaviour. There are many possibilities. For example, stop lamps and direction indicators can be mounted higher on the vehicle perhaps even above roof level, so that they can be seen more easily by other drivers; stop lamps might be made to show the degree of braking effort being applied, and other ways of giving more information about slowing down and stopping might be developed if the need for them was established. Uniformity of signalling is an important aid to safety both nationally and internationally. We see co insuperable technical problems in the design of signalling equipment. But we suggest there is a need for further research to decide, in the light of foreseeable traffic conditions, what information needs to be conveyed from one road user to others and to traffic controllers, and the best ways of communicating it promptly and unmistakably.

At present a driver must rely on his own physical senses and judgment when driving. Devices capable of warning him that he was steering a collision course, was travelling too fast or too close to other vehicles, and radio instructions from traffic controllers about traffic and road conditions ahead, are all potential aids to safety. Some of these things[5] are already in experimental use in this country and abroad. The prospects for automatic vehicle control are examined in Chapter 11. The problem of detecting potential sources of danger is common both to automatic control and to warning systems, but with a warning system, control of the vehicle would remain in the driver's hands, so that a less precise means of detection might still be an aid to safety. For example, a guidance system might be used to enable a driver to steer by instruments. This, together with additional very bright rear-lamps for use only when visibility was poor might reduce the strain and danger of driving in fog. Proximity warning devices[6] may also offer a solution to the problem of avoiding multiple collisions in bad visibility.

(5) For example, the driver aid, information and route-ing system (DAIR) now being developed by General Motors Research Ltd, Warren, Michigan. This system provides a radio link between the driver and an information centre and uses a sequence of magnets buried in the road surface, constituting an identifying code, and low frequency repeaters at the roadside to convey spoken or coded messages to and from the vehicle.

(6) See glossary.

Plate 7-4 'Better street lighting is already being provided on main traffic routes in towns'

7.3 Protecting vehicle occupants

The most numerous and serious accidents – about two-thirds of the total – are head-on collisions with other vehicles or with obstacles. The next most serious are side-impacts, which may severely injure the occupants nearest to the point of impact. Least serious are rear impacts and overturning

The vehicle occupants may get hurt by striking the inside of the car, by being ejected, or by being crushed. The most dangerous injuries are to the head, neck and body. If new patterns of vehicle use develop[7], the relative importance of different accident types may change, but it is still highly probable that injuries will mainly be caused by impact with the inside of the vehicle, and that the most important principles of protection will remain the same as at present.

One approach to the problem of protecting the vehicle occupants is to rely simply on increases of structural strength of the passenger compartment to prevent crushing. But this will not prevent the occupants from being injured by striking the inside of the car, for although padding and the elimination of sharp internal edges and projections are very desirable, they are not, in themselves, sufficient protection. All other approaches to the problem are based on the principle of reducing the deceleration force applied to the occupants, by allowing an occupant's body the largest possible stopping distance With a safety belt, or harness, this distance is obtained in two ways:

(a) the occupant is tied to the passenger compartment and decelerates with it; and

(b) the harness itself stretches considerably, often a foot or more. In medium or large-sized cars, the front end may crush as much as three feet in a head-on collision, so that, with a safety harness, the occupant's total stopping distance can be very much greater than is allowed by the stretching of the harness[8]. With smaller cars the crushable length of vehicle in front of the passenger compartment may be very much less, perhaps as little as six inches. Protection of the occupants must then be obtained almost entirely from the stretching of the harness. Although small cars create more difficult safety problems than larger ones, it should be possible to protect the occupants adequately by this means at normal town traffic speeds. No other approach used so far, for example, a yielding steering wheel or a padded dashboard, can

(7) As for example, the widespread use of citycars on segregated networks, which is discussed in Chapter 3.

(8) See *Safety Cars* by G. Grime. Road Research Laboratory Report, No. 8, 1966.

compare with a safety harness in providing decelerating distance. In addition the flexible webbing of the harness with its relatively large surface area is well adapted to applying large forces to the body without causing injury. An alternative approach might be to incorporate a buffer system in the mounting of a safety seat. The seat, with the occupant held in it, could then move forward against a constant resistance over a short distance.

Protection by harness-stretch or seat movement of this kind means allowing enough room, say 18 inches, in front of each vehicle occupant. This is particularly important for the head, which is very vulnerable. It also means either doing away with the steering wheel and column in their present form, or making them collapsible. The latter presents few engineering difficulties and the former might result from re-arrangement of the controls for other reasons.

Means of holding the occupants in place are also of value in overturning accidents, and in all types of collision, but especially in side impacts, they have the additional value, along with burst-proof locks and doors, of helping to prevent the occupants from being thrown from the vehicle. This is particularly so of devices which incorporate a lap strap.

But neither safety belts nor safety seats are any use unless the car occupants are fastened into them. As with all safety devices that are at the user's option, this is fundamentally a problem of attitudes and behaviour. If the equipment is easy to use and comfortable to wear more people are likely to use it. There may, however, be scope for developing a close-fitting device to replace the present seat-belt. Additionally, it would be technically feasible to make it impossible to start up or move off unless the occupants were strapped into their seats.

The chief hazard in side impacts is to occupants nearest the point of impact who may be violently thrown or even crushed if the side of the car is heavily deformed. Practical methods of protection in a small car include strengthening the sides of the vehicle and filling them with an impact absorbing material such as honeycomb metal, but these are of little value if a small vehicle is struck by a much heavier one. Incorporation of a substantial roll-over bar would seem in some circumstances to offer better prospects of protection. Alternatively, the car might be designed so that the chassis formed a protective frame around the passenger compartment. However, this would probably mean having deep door sills, which would make getting in or out of the car difficult. All these factors point to the need for vehicles to be designed from the outset to incorporate protection for the occupants.

7.4 Protecting other road users

Vehicle design should also aim to minimise injury to pedestrians or cyclists who run into or are hit by vehicles. The hazards of sharp projections, in the form of ornamentation, radiator and tail forms, headlamp shields and handles, and the desirability of rounding essential projections such as bumpers are well known. Some goods vehicles are, by their design, particularly prone to have sharp and potentially dangerous edges and projections. In our view more could be done to eliminate such features.

7.5 Conclusions

In recent years there has been a growing awareness both among the general public and in the motor industry, of the need for safety as a feature of vehicle design. At the same time there has been a much greater understanding of the causes of injuries from road accidents, and of the means of preventing them or minimising their severity. Good engineering design, resulting in a stable, reliable vehicle with good handling qualities, coupled with the use of properly-designed safety harness or safety seats can help to reduce the risk of accidents and minimise their consequences. But less is known about the effects of signalling and warning devices on the incidence of traffic accidents, and we suggest this warrants further investigation.

Plate 7-5 The Cox Safety Seat

8 Noise

8.1 Noise and the Wilson committee

Vehicle noise is audible both inside and outside vehicles. We have concerned ourselves mainly with external noise but we have also considered internal noise in so far as it may be a factor – through causing tiredness – contributing to accidents.[1]

Noise was the subject of recent investigation by the Wilson Committee[2] which dealt fully with the nature, sources and measurement of noise, people's reaction to it and its general effects on health. We have taken the work of the Wilson Committee as a basis for our study, and have gone on to consider the vehicle design implications arising from the Committee's recommendations.

In dealing with motor vehicle noise, the Committee found it desirable to relate the subjective annoyance caused by noise to objective standards of measurement and they accordingly arranged experiments in which the external noise from a range of vehicles was both measured on a noise meter and assessed on a six-point scale – that included ratings of 'tolerable' or 'unacceptable' – by a panel of observers. As a result of this and other evidence, the Committee recommended a maximum permissible noise level of 85 dB(A)[3] for all new vehicles excepting motor cycles and other two wheelers, for which a level of 90 dB(A)[4] was proposed. They also recommended that these limits should be reviewed after three years and reduced progressively.

The limits proposed by the Wilson Committee were based on the test method detailed in British Standard, BS 3425 1961 and were embodied in draft regulations issued by the Ministry of Transport in 1963; these have not yet become law. Many foreign countries have already legislated against excessive vehicle noise, some rely on the subjective assessment of the enforcement officer, others use measuring instruments in specified conditions. The need for standardisation led to a recommendation (R 362) in 1964 by the International Standards Organisation on the

Plate 8-1 Motor cycle noise tests in progress at the Motor Industry Research Association

methods of measuring vehicle noise. The adoption of this method[5] resulted in a re-appraisal of the proposed British limits; those for cars and motor cycles remain as recommended by the Wilson Committee, but for commercial vehicles a revised figure of 87dB(A) has been put forward for consideration.

Tests[6] during the last few years on nearly 100 cars showed that about three-quarters of the models tested made no more – and often much less – noise than the proposed limit of 85dB(A) under both the above methods of test. All but one of the others were high performance cars, with noise levels ranging from 87 to 96dB(A). With motor cycles nearly half the models exceeded the 90dB(A) limit. Whilst a few were notably quiet, others were very noisy (particularly the higher powered sports models), the levels recorded ranging from 74 to 100dB(A). Buses and goods vehicles were least satisfactory, only about a third being quiet enough to meet the suggested limit of 87dB(A). The levels recorded ranged from 81 to 96dB(A). Many of those with noise levels above 87dB(A) were, not unexpectedly, heavy goods vehicles powered by diesel engines.

From all this, we are satisfied that there is still considerable need for reduction in the noise from some high performance cars, from motor cycles and from heavy goods vehicles. In many cases, reductions of 5 to 10dB(A) would be necessary to meet the Wilson limits as indicated in figures 8.1, 8.2 and 8.3.

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(1) Burns, W., *Hearing and noise*, Pergamon Press, Oxford.

(2) *Report of the Committee on the Problem of Noise*, Cmnd. 2056, HMSO, 1963

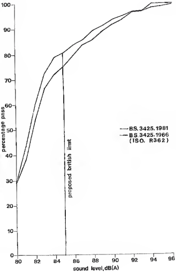
(3) The Wilson Committee adopted 'decibels on the A scale' (dB(A)) as the means of measuring vehicle noise, i.e. readings on a sound level meter having particular characteristics. The difficulties of objective noise measurement are fully explained in the Wilson report, but briefly, a noise meter only reacts to the physical characteristics of noise, i.e. the frequency and intensity of the pressure waves which constitute noise, and takes no account of the subjective reactions of people, which are fundamental to general ideas of loudness. This means that a noise meter does not measure directly what is generally understood by the loudness of any noise, but merely provides a means of comparing the loudness of noises of similar character. The use of the weighting network from which readings are quoted on the 'dB(A)' scale provides a means of making measurements that correspond reasonably well with a subjective assessment of loudness. Furthermore, as the decibel scale is logarithmic, quite small variations in meter reading in the range of vehicle noise can represent significant changes in sound intensity. Doubling the intensity, in terms of sound wave pressure, adds only 3dB to a decibel reading. Doubling the loudness of a sound, assessed subjectively, represents an increase of about 10dB. The decibel scale adopts the threshold of hearing as being 'OdB' and on this basis the scale extends to about 120dB, which represents the threshold of pain.

(4) This takes account of the difference in the way a noise meter reacts to motor cycle noise compared with other vehicle noise which indicates that the limit for motor cycles should be somewhat higher than for other vehicles.

(5) Incorporated in BS 3425 1966 which is in substantial agreement with ISO recommendation R 362.

(6) Mainly by the Motor Industry Research Association and the Ministry of Transport.

Percentages of models which would exceed indicated sound level



Figare 8:1 Motor cars

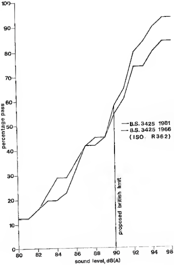


Figure 8:2 Motor cycles

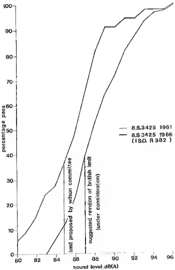


Figure 8:3 Commercial vehicles

The nature of noise is such that a loud noise masks a less intense one. The process of noise reduction from vehicles therefore involves identifying sources of noise in order of importance and reducing the noise from each, in turn, to an acceptable level. Achieving this obviously becomes increasingly difficult and the limit is reached with such noise as that arising from the interaction between the tyres and the road surface. However, in most vehicles, the predominant source of noise at present is the power unit – the exhaust, air intake and engine itself – and it is on this that most research work has been, and is still being, concentrated. The chief ways of reducing noise are by reduction at source, by suppression in the path between source and receiver, or both. Luxury cars and some types of motor cycle demonstrate that noise can be reduced a great deal, but silence is obtained only at a cost in money and perhaps in some loss of performance.

8.2 External noise from the power unit

The amount of noise from an engine depends on its power output, its speed and many design factors. The importance of particular design features for reducing noise will obviously vary between different engines but it remains worthwhile considering separately exhaust and air intake noise and direct engine noise.

8.2.1 Exhaust noise

A great deal of research has been done during the last few years on ways of reducing the noise through and from the exhaust system. As a result, it is now generally possible, by using large well-designed silencers, to reduce exhaust noise, with negligible loss of power, to a level at which it is masked by engine noise. However, an efficient silencing system adds weight, bulk and cost, and the practical difficulties of housing the extra bulk can be acute where space is limited. Technically, the reduction of exhaust noise now presents no insuperable design problems, but cost remains an important factor.

8.2.2 Air intake noise

Unless it is properly silenced, air intake noise is readily audible. When exhaust noise has been reduced to a low level, air intake noise may become predominant, but it can generally be dealt with by intake silencers of adequate volume and design to control the offending frequencies.

8.2.3 Engine noise

As exhaust and air intake noise levels are reduced, engine noise tends to become predominant, particularly with diesel-engined commercial vehicles, motor cycles and some high performance cars. Of these, the commercial vehicle is probably the worst.

The reduction of engine noise is difficult and, until recently, has been given comparatively little attention. It arises from many sources, including the combustion process, valve gear, cooling fan, timing chain or gears and the water, oil and fuel pumps. Vibration and roughness due to unbalanced forces also generate noise. All sources radiate to the surrounding air via the engine structure, flywheel housing, crankshaft pulleys and sheet metal covers. Practical solutions are difficult to find, are costly and may involve a good deal of re-design.

8.2.4 Containment of engine noise

Containing engine noise appears attractive as it involves no re-design of the engine or its auxiliaries. But complete enclosure creates problems with cooling, control lines and services and access for maintenance, and in practice partial shielding rather than complete enclosure is usually all that is possible. The efficiency of acoustic shielding is increased by the use of sound absorbent materials which reduce noise 'build-up' in what would otherwise be a reverberant enclosure; they also have the advantage of lightness. Protection of these porous materials against impregnation by fuel and oil, to avoid a fire hazard is necessary.

It is difficult to assess accurately the extent to which engine noise can be reduced by practical methods of enclosure. But recent experimental work on diesel buses and lorries has shown that improvements of 6 to 8dB(A) are likely using modern foam plastic materials. This may be enough to bring most commercial vehicles with engines at present in use within the limit of 87dB(A) now being considered. Further reductions will need changes in the design and construction of the engine and its auxiliaries. More powerful engines are coming into use and they present a more difficult problem.

8.2.5 Reduction of engine noise at source

Light engines using higher speeds, compression ratios, and peak combustion pressures have made the engine structure an important source of noise. The degree of stiffening achieved by conventional changes in the method of construction is likely only to affect the character of the noise, to reduce its volume needs a more radical approach.

Some recent research work[7] on experimental diesel engines has shown that engine structural noise can be reduced by about 10dB(A) without increasing the engine weight significantly, by using either a skeleton load-carrying framework covered in materials providing high internal sound damping or by greatly increasing the stiffness of the engine walls by using very thick lightweight material, e.g. magnesium. Although this work has clearly demonstrated the principles, it is difficult to foresee how these rather complicated and costly techniques can be applied economically to production engines. There is, however, some scope for the use, in more conventional engine structures, of alloys with much better internal sound damping properties, but they are likely to be expensive.

Noise from the combustion process is particularly pronounced in diesel engines, where the abrupt rise of cylinder pressure gives the characteristic 'diesel knock'. Attempts to smooth combustion noise have met with only partial success and although work on this continues a big reduction in combustion noise from the diesel seems unlikely. Mechanical and impact noise can be reduced by smaller clearances between working parts and attention to the design of, for example, gear trains and other forms of drive but, again, there does not seem to be much prospect of big reductions in mechanical engine noise. This is especially so for diesel engines, with their heavier moving parts and externally-mounted fuel injection equipment.

Sheet metal engine parts such as the timing and rocker covers and the oil sump are often noise radiators. Double skin construction, with a sound deadening intermediate layer, can reduce noise by up to 6dB(A). Insulating the front crankshaft pulley from the crankshaft, or using other methods of driving the engine auxiliaries, can reduce radiation from the pulley. Of the accessories, the cooling fan is probably the greatest source of noise. Lowering the blade tip speed, using variable pitch blades, or thermostatic control so that the fan operates only at high water temperatures, reduces fan noise.

8.3 Other sources of external noise

8.3.1 Transmission systems

As noise from the engine is reduced, that from the transmission may become predominant. Gear boxes and rear axles are generally much quieter than they used to be, but there is scope for improvements with some commercial vehicles.

[7] T. Priede, A. E. W. Austen and E. C. Grover *Effect of engine structure on noise of diesel engines*, Institution of Mechanical Engineers paper, 1965.

8.3.2 Brake squeal

The Wilson report referred to brake squeal but the problem has now been largely overcome by changes in brake design and materials.

8.3.3 Door slamming

Noise from door slamming is being reduced by better door and seal design and locks that enable doors to be shut without slamming. This nuisance is to some extent a matter of user habit, but it would be possible to eliminate slamming altogether if doors were designed to be closed by a movement of the handle

8.3.4 Vehicle loads

The noise from loads arises from goods vehicles. Obviously such loads as empty crates, glass bottles, metal tubes, etc., can be a big source of noise. Worthwhile reductions can be achieved by improved packaging – for example, by avoiding metal to metal contact, using sound deadening material for packing and securing the load firmly. Almost any load can be dealt with adequately but the method of doing this is perhaps more a matter for the packaging industry, and manufacturers and distributors of goods than it is for the vehicle designer.

8.3.5 Chassis and body structure

The transmission of noise through the chassis and body can increase considerably the noise from goods vehicles and buses. Some types of goods vehicle body act as sounding boxes, with the drumming of large unsupported body panels. Resonance through the bodywork can raise the overall noise level by as much as 6dB(A). Very little work has been done on this subject. There are inherent difficulties in reducing external chassis and body noise from large commercial vehicles that do not have variable rate springing and are subject to hard treatment. Such vehicles often make more noise when empty than when laden. Useful reductions can be made by the use of sound deadening materials and rubber bushings to isolate the engine, gearbox, wheels and axles from the chassis or body. Further reductions will probably need the use of more sophisticated suspension systems and body construction techniques.

8.3.6 Coasting noise

When other sources of vehicle noise have been reduced enough, coasting noise(8) – chiefly from tyres – can become a significant part of total noise. Tyre noise is aggravated by modern adhesive tyre treads and road surfaces designed to give maximum grip and is much worse at higher speeds. Above about 45 mph, tyre and wind noise become louder than engine noise, particularly with heavy vehicles. Some reduction may be possible but we do not foresee much improvement. Measurements(9) on some current production vehicles suggest that at speeds up to 30 mph coasting noise may reach 70 to 75 dB(A) for cars and 75 to 80 dB(A) for medium sized commercial vehicles, the lower limits referring to dry roads and the higher to wet roads. These levels represent the practical limits for the reduction of vehicle noise for cars and medium sized goods vehicles; the heaviest goods vehicles are unlikely to get down to the level of 80dB(A).

8.4 Internal noise

A good deal of progress has already been made in quietening the inside of cars, so that this is generally no longer a major design problem even where a diesel engine is used, except in very small cheap cars. Modern sound insulation techniques and sound absorbing materials could enable such vehicles to be made acceptably quiet, at the expense of some increase in weight and cost.

In commercial vehicles the problem is more difficult, particularly where the driver's compartment is almost immediately above the engine. The noise level in the driver's cab is often too high and research is now being done on the reduction of interior noise in commercial vehicles. Until recently, very little use has been made of sound absorbing and insulation materials, except in luxury coaches. It seems to us that there is still considerable scope for improvement in goods vehicles generally and in some buses. We consider a high level of noise in the driver's compartment to be a cause of fatigue and reduction of it to an acceptable level should be a normal design aim. Methods of achieving it must, however, recognise the need for the driver to be able to hear warning signals from other vehicles.

8.5 Legislation

Noise from individual vehicles (except noise from door slamming) is at present subject to control by regulations made under the Road Traffic Acts. However, without a defined and measurable standard of what constitutes excessive noise, it is difficult to enforce the regulations which are, therefore, of limited value. Reducing vehicle noise is not necessarily of interest to the manufacturer or the user as it can increase both weight and cost. As each source of noise is tackled it becomes increasingly difficult and costly to obtain further reductions and it may be that for some sorts of vehicles the measures needed to achieve acceptable noise levels will prove expensive – perhaps up to £100 for a heavy vehicle. More effective regulations, including perhaps regulations relating to noise levels in commercial vehicle cabs, are therefore essential if such improvements are to be achieved. Progress has undoubtedly been retarded by the delay in bringing into force the Minister's draft regulations of 1963 which would by now have applied to the 2 million new vehicles registered since the beginning of 1965 (although a large proportion of these are, of course, already within the proposed limits). Moreover, whilst the proposed limit of 90dB(A) for motor cycles is intended to take account of the difference in the way a noise meter reacts to motor cycle noise compared with other vehicle noise, it could result in some small machines being noisier than they need be. In our opinion 'mopeds' and other lightweight motor cycles should be rated at a lower level because they often operate at maximum power and their peculiar noise characteristics can cause considerable annoyance.

8.6 Conclusions on vehicle noise

Design can contribute significantly to making vehicles quieter. For the future, it seems likely that further reductions in noise beyond those needed to meet the initial Wilson Committee limits will be achievable for most sorts of vehicle, but only with some difficulty and expense. The need for better performance and the trend towards heavier commercial vehicles is demanding more powerful diesel engines than those now in use. Engine noise increases with power and diesel engines of 250 to 300 bhp may emit between 90 and 100dB(A), so it may not be easy to keep the noise from heavy commercial vehicles within the limit of 87dB(A) at present being considered. If such noise levels for all goods vehicles prove impracticable, it may be desirable to exclude 'non-conforming' vehicles from areas, such as town centres, where the noise problem is most severe. In the long term, heavy goods vehicle noise might be significantly reduced if, for example, the gas turbine or the fuel cell became generally available for automotive use. The prospect of this is discussed in Chapter 10.

Electric vehicles can be very quiet when running and make no noise at all when stationary, so they are particularly suitable for towns. We consider the prospects for electric vehicles generally in Chapter 10 but it seems to us that performance limitations prevent electric vehicles making a significant contribution at present.

(8) See glossary.
(9) By the Motor Industry Research Association.

8.7 Traffic noise

This chapter has related to the noise levels from individual vehicles, but noise levels in streets represent the cumulative effect of all the traffic. If two vehicles close together are making the same amount of noise, the total noise is about 3dB more than that from one of them. Within a group of vehicles, the resulting noise level is nearly always determined by the noisiest individual vehicle, as this masks the noise from the quieter ones. Similarly, the cumulative effect of the noisier vehicles in a group may be greater than the noise from a much larger number of quieter ones and if out of, say, 100 vehicles 20 are appreciably noisier than the rest, quietening them will have more effect than dealing with the other 80 vehicles.

The London Noise Survey[10] of 1961–1962 showed that at over four-fifths of the points surveyed the predominant noise was that of road traffic. On main traffic routes the noise levels at peak periods at the kerbside were about 90dB(A) and even in side streets the level exceeded 75dB(A) for 10% of the time. We are not in a position to say to what extent this is likely to be changed by reducing the noise from various sorts of vehicle, for a lot depends on the volume and composition of traffic and the way in which vehicles are driven. More research will be necessary to establish what the maximum permissible level of traffic noise should be, but it has been suggested that an overall reduction of about 10dB(A) in traffic noise – as opposed to individual vehicle noise – would make it much more tolerable. One of the main causes of additional noise in towns is acceleration in the lower gears. The need for this is influenced by the number of intersections, steep gradients, and the general level of traffic congestion, and can be alleviated not only by quieter vehicles but also by freer flowing traffic.

In considering noise inside buildings, the Wilson Committee suggested that in towns, the internal noise level by day should not exceed 50dB. If an allowance of 20 to 30 dB is made for the insulating effect of the building when the windows are shut, this would mean that the external noise level should not exceed 70 to 80dB. A maximum traffic noise level of 75dB(A), 20 ft. from buildings, would therefore be consistent with desirable noise levels inside buildings, provided windows were shut. If windows are open, the insulation from outside noise is greatly reduced and even a maximum noise level for individual vehicles of 70dB(A) (which many of the heaviest vehicles could not reach) would then still be too high to achieve the desired level of noise inside buildings. This suggests that to meet the Wilson limits inside buildings either the noisiest vehicles will have to be banned from very closely built-up areas or else such remedies as air conditioning and sound proofing of buildings will be needed. This emphasises the importance of tackling the problem of noise by means such as improved buildings, freer-flowing traffic and care in the planning of major highways in relation to other land uses, in addition to developments in vehicle design.

Very little is known about the value people place on relative freedom from traffic noise and it is not part of our job, nor have we been able, to assess the extent to which the community is prepared to pay for quieter vehicles. For the present, we are satisfied that with current techniques vehicles can be designed to comply with the noise limits which have been proposed and that when this is done there will be a worthwhile reduction in the peak levels of traffic noise in cities.

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[10] See Chapter IV of the *Report of the Committee on the problem of Noise*, Cmnd. 2056 HMSO, 1963.

9 Air pollution from motor vehicles

A great deal of research is at present being done on pollution from motor vehicles, much of it arising from conditions in the United States. We have reviewed the pollution situation as it exists in the United Kingdom, with particular regard to the likely growth of traffic and to changes in traffic conditions. We have gone on to consider how the problems in this country are being tackled and what changes in vehicle design could help in solving them.

Not all pollutants are considered objectionable. If the exhaust from, say, a diesel bus were not only invisible but had a fragrant aroma not many people would complain about it. The cigarette smoker enjoys the smoke he inhales (even though it may harm him and be a nuisance to other people) and few would worry about the pollutants released by a steak cooking on a charcoal grill. Clearly, a pollutant need not necessarily be a nuisance. But the pollutants from engines running on petrol or diesel fuel are far from fragrant; they are unpleasant, obnoxious and potentially harmful.

Air pollution from the use of the roads occurred long before the advent of the motor vehicle. But the nature of pollution from the internal combustion engine and the growth in the number of vehicles are now making more acute the problems created by their contribution to atmospheric pollution in towns. The emission of smoke, vapour, oily substances, and so on were prohibited soon after the introduction of mechanically propelled vehicles, but it is only comparatively recently that much work has been done on the causes, effects and methods of controlling such emissions.

In most towns in this country, the motor vehicle is not the major source of air pollution. But the Clean Air Act of 1956 (which does not apply to motor vehicles) is resulting in reduced pollution from coal-burning domestic and industrial appliances which have, in the past, created most of the air pollution (see figure 9:1). The number of motor vehicles registered is expected to double before 1980, and, if nothing is done, the motor vehicle will become an increasingly important contributor to air pollution in towns. It is already almost entirely responsible for air pollution from carbon monoxide.

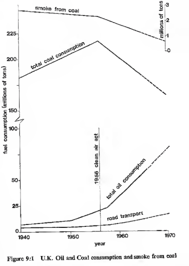

Figure 9:1 U.K. Oil and Coal consumption and smoke from coal

9.1 The pollutants from engines and the nature of atmospheric smog

Internal combustion engines burn fuels that are compounds of carbon and hydrogen. Ideally, the fuel could be burned completely in air to give only carbon dioxide and water and there would then be no air pollution problem. But this is an ideal that cannot be attained in motor vehicles and some pollutants are bound to be produced. These may include carbon monoxide, smoke,[1] hydrocarbons, oxides of nitrogen, oxides of sulphur, lead and aldehydes.

Although both petrol and diesel engines emit the same kinds of pollutants, the proportions in the exhaust are different because of differences in the ways the engines work. In almost all petrol engines, the fuel is metered by the carburettor, mixed with air, drawn into the engine, compressed, ignited by the sparking plug and burnt to give the power stroke, after which the products of combustion are expelled via the exhaust system. The mixture strength, or air/fuel ratio, is about that needed theoretically to burn the fuel (namely 14·6:1). But this precise mixture is difficult to achieve under all operating conditions and the consequent incomplete combustion results in appreciable quantities of pollutants. In the diesel engine, air alone is drawn in and the compression ratio is about twice that of the petrol engine. A full charge of air is always drawn in and fuel is injected into each cylinder when the air is fully compressed and its temperature has risen enough to cause the fuel to ignite. Power is regulated by altering the amount of fuel injected. The power and exhaust strokes follow, as in the petrol engine. Even with the richest mixture the air/fuel ratio is about 20:1 and there is therefore ample oxygen to burn all the fuel supplied.

(1) By 'smoke' we mean visible exhaust fumes; they are made up chiefly of carbon particles.

The levels of pollutants in the exhaust of petrol and diesel engines vary widely from one type of engine to another and also between engines of the same type under different operating conditions. The concentrations quoted in figure 9 2 for the more common pollutants are therefore no more than typical average values for vehicles in a reasonable state of maintenance.

Figure 9:2 Typical concentrations of pollutants in exhaust gases

Engine Operation	Idling		Accelerating		Cruising		Decelerating	
Type of Engine	Diesel	Petrol	Diesel	Petrol	Diesel	Petrol	Diesel	Petrol
Carbon Monoxide %	Trace	7·0	0·10	3 0	Trace	4·0	Trace	3·0
Hydrocarbons[1] ppm[2]	220	820	110	700	55	500	160	4,400
Oxides of Nitrogen ppm	60	30	850	1,050	250	650	30	20
Aldehydes ppm	10	30	20	20	10	10	30	300
Sulphur dioxide %[3]	—	—	—	—	—	—	—	—

[1] Total hydrocarbons, as measured on hexane sensitised non-dispersive infra-red gas analyser.
[2] ppm = parts per million.
[3] The average concentration of sulphur dioxide in the exhaust is about 18 ppm for diesel engines and 6 ppm for petrol engines

9.1.1 Los Angeles and London smog

The importance of air pollution from a large number of motor vehicles was probably first realised in Los Angeles where, about twenty years ago, an eye-irritant type of 'smog' became increasingly evident. This smog, which occurs in the summer and autumn, forms during the first hours of sunshine and becomes more and more visible as a brown haze. The smog is due to the photo-chemical action of strong ultra-violet light on hydrocarbons and oxides of nitrogen from motor vehicles. In Los Angeles the problem is particularly acute[2] because there is a large car population, while the climate and the topographical features of the region result in frequent temperature inversions[3] over the city, thus preventing dispersion of the pollutants.

Plate 9–1A A clear day in Los Angeles

Plate 9–1B A 'smoggy' day in Los Angeles

[2] Photochemical smog may occur on as many as 200 days in the year in Los Angeles.
[3] Temperature inversion is a meteorological condition which occurs when a blanket of warm air traps the colder air underneath and the normal air turbulence ceases.

The basic ingredients of Los Angeles smog are strong sunlight, stable air and a high density of large and powerful motor cars. Photochemical smog occurs sometimes in other sunlit cities; but in this country cloud and, until recently, the screen of smoke has prevented any significant occurrence of it in our towns. If, however, the Clean Air Act results in the abolition of smoke and if the rapid growth in the vehicle population continues, it seems likely that on some bright calm summer days photochemical smog will occur here.

London type smog consists mainly of particles of smoke and water-vapour with the addition of sulphur compounds. It can occur on cold misty days, or at night, in any town where a good deal of coal and oil are being burned. This type of smog produces poor visibility and can cause severe bronchial irritation. It is thus very different from Los Angeles photochemical smog (see figure 9:3) and, in particular, owes very little to the presence of the motor vehicle.

Figure 9:3 Comparison of London and Los Angeles Smog

	London type	Los Angeles type
General	Old phenomenon – combination of smoke and fog.	New phenomenon – caused by photochemical reactions.
Components	Smoke, sulphur oxides, nitrogen oxides, carbon monoxide, water vapour.	Hydrocarbons, nitrogen oxides, ozone, carbon monoxide.
Fuel sources	Coal, coke, fuel oil.	Motor spirit, gas, oil.
Atmospheric Conditions		
Season	Winter	Summer–Autumn
Temperature	Below 40°F (4·5°C)	Above 75°F (24°C)
Humidity	High	Low
Sun	Overcast	Bright
Ozone concentration	Low	High
Time of occurrence	Day and night – continuous	Daytime only.
Visibility	Very low (less than 50 yards)	Moderate (half mile)
Toxicity	Bronchial irritation, which in the aged and ill can lead to death.	Eye irritation, no evidence of serious effect on health.

9.2 The concentrations of pollutants in streets

In the popular mind, black smoke from diesel engines causes the most concern, probably because it looks and smells unpleasant and can jeopardise road safety by obscuring the view which the driver of a following vehicle has of the road ahead. But we have attempted to examine more systematically the nature and the extent of pollution from vehicles.

The local level of pollution in the air is a balance between the rate at which pollutants are emitted from, for example, vehicles and industrial and domestic premises, and the rate at which they are dispersed which, in turn, depends mainly on air movement. In a city, air movement – both horizontally and vertically – is influenced by many factors of which the chief is wind, which reduces pollution in proportion to its speed. During temperature inversions,[4] when the normal turbulence of the air ceases, pollution accumulates in pools and concentrations may then reach twenty to thirty times the mean annual levels (see figure 9:4). However, in more normal conditions, natural dispersion of vehicle exhaust gases at present prevents them reaching undesirably high concentrations, except in some of the busiest city streets. An increased use in future of underpasses and streets linked more closely into buildings would, however, aggravate the problem.

The pollution created by the motor vehicle is more local than that from other sources. Measurements of pollution in busy towns show that in a quiet street only 50 yards from the main traffic stream there is little or no measurable pollution from motor vehicles. The people most likely to suffer from pollution caused by motor vehicles are therefore, pedestrians and the occupants of vehicles in congested traffic.

(4) In this country, such inversions are more likely to occur in the winter and to be more persistent than those which occur in the summer.

Figure 9:4 The concentration of pollutants in city streets

Pollutant	Toxic Limit in Air (8 hour exposure) or Maximum Allowable Concentration	Maximum Concentration Found in City Streets	Typical Winter Concentrations in City Streets
Smoke (mg/m^3)	—	10	0·2 to 0·3
Carbon monoxide (parts per million)	100 (1)	360 (2)	10 to 25 (2)
Sulphur dioxide (ppm)	5	2·0	0·2
Sulphuric acid (mg/m^3)	1	0·7	0·01
Nitric oxide (ppm)	25	1·1	0·05
Nitrogen dioxide (ppm)	5	0·2	0·03
Hydrocarbons			
3:4 Benzpyrene ($\mu g/m^3$)	—	2·22	0·05
Lead ($\mu g/m^3$)	200	4·8	1·1
Aldehydes			
Formaldehyde (ppm)	5	—	—
Acrolein (ppm)	0·5	—	—
Acetaldehyde (ppm)	200	—	—

(1) In the USA the toxic limit is now 50 ppm; this is likely to be adopted here.
(2) As measured close to traffic in busy streets; concentrations much lower in general atmosphere

In the United Kingdom, most of the investigations into the motor vehicle's contribution to atmospheric pollution have been carried out by the Air Pollution Research Unit of the Medical Research Council and the Warren Spring Laboratory of the Ministry of Technology. Measurements have been made at the road-side in London, Manchester and other places where it was expected that vehicle exhaust gases would be a significant source of air pollution. Figure 9:4 compares the maximum concentrations found at these selected sites with the 'background' concentrations at control sites and with the industrial maximum allowable concentrations.[5]

Pollution can be undesirable because it is unpleasant or because of dangers to health. On the latter we have taken the advice of the Medical Research Council. The medical considerations we quote are accordingly based on the information from the Director of their Air Pollution Research Unit. Inevitably, information is sometimes incomplete and research work continues.

Motor vehicles' exhaust products can cause death if they are inhaled in high enough concentrations. However, we are more concerned with the effects on the health, performance and well-being of drivers, pedestrians and others who are exposed to the day-to-day levels of pollution caused by vehicle exhausts. Much research has been done and much has been written about the real, suspected and imagined effects of vehicle exhaust gases on men and on animals and we have been impressed by the inevitable difficulty of establishing causal relations between particular levels of pollution and particular medical consequences. However, as a result of work by the Air Pollution Research Unit, and others, some imagined problems connected with vehicle exhausts are now seen to be without foundation, or are clearly less serious than was thought, but carbon monoxide is now seen as a potentially serious health hazard. The concentrations of pollutants found in city streets and their medical significance are discussed in Appendix 'C'.

From all the evidence and other information available to us, we are satisfied that the main aspects of pollution from motor vehicles that are important are carbon monoxide from petrol engines as a possible health hazard; smoke from diesel engines, not as a health hazard but because of the road accident risk and because it is unpleasant; and hydrocarbons and oxides of nitrogen, from diesel and petrol engines, as a possible future cause – when there is less pollution from other sources but more from vehicles – of occasional photochemical smog of the Los Angeles type. There remains the additional possibility, on which medical work is proceeding, that some pollutants may interact in the human body to produce effects over and above the sum of the individual direct effects. This could obviously lead to a new view about the significance of individual motor vehicle pollutants.

9.3 The causes of, and remedies for, pollution from internal combustion engines

The level of atmospheric pollution depends, among other things, on the total volume of vehicle exhaust gases and the concentration of pollutant in them. There are, therefore, several ways of reducing the level of air pollution from motor vehicles. We have rejected, for purposes of this study, simply reducing the numbers of vehicles in towns. The use of new forms of propulsion – particularly electric traction – we consider in Chapter 10. We also consider later reducing the size of vehicles and their engines and changes in traffic conditions. At this stage, we consider changes in the design of the engine or its fuel that might reduce the pollutants from existing forms of internal-combustion engine. Some pollutants, particularly hydrocarbons, are emitted from the crankcase ventilator, fuel tank and carburettor of petrol engines. But most pollutants, from both diesel and petrol engines, come from the exhaust. In the following paragraphs, in which we consider the causes of, and remedies for, pollution from engines, we use as a convenient yardstick of performance the proportion of particular pollutant in the exhaust gases.

9.4 Pollution from diesel engines

A correctly rated and properly maintained diesel engine produces very little smoke under normal operating conditions. The basic cause of excessive smoke from diesel engines is over-fuelling, which can arise from deliberate mal-adjustment of the engine to obtain more power or from poor maintenance. A more detailed description of the causes of pollution from diesel engines is given in Appendix 'D'.

The most important factor in preventing diesel engines from producing smoke is a high standard of maintenance. Here, however, we consider the possible contribution of engine design and fuel developments.

It seems, at first sight, that a simple solution would be to remove the smoke from the exhaust system. Various physical methods of doing this have been tried including filtration, electrostatic precipitation[6] and collection in cyclones[7] and scrubbers[8], but none has proved satisfactory. The combustion of smoke, with and without a catalyst, has also been explored but without much success. The main reason is that not much of the smoke will burn because of the low exhaust gas temperature of most diesel engines; this also reduces the efficiency of any catalyst. We are satisfied that rather than attempting to find a cheap and practicable method of removing smoke after it has been formed, it would be better to avoid the creation of excessive smoke in the first place.

9.4.1 Anti-smoke additives

Additives that have recently become available reduce smoke generation by acting as catalysts and promoting more complete combustion. Present additives are comparatively expensive (they cost about 1½d per gallon of fuel treated) and this may tend to discourage their use, but development is at an early stage and it may be that additives that are even more effective and also cheaper may be produced.

These additives clearly reduce the tendency of diesel engines to smoke. They thus offer a means of reducing black smoke (at some extra cost), or up-rating engine output with the same level of smoke. They may also have the desirable effect of making engines less sensitive to lack of maintenance. If they were added to all diesel fuel, manufacturers might then design engines to take advantage of their properties, continuing to rate an engine as close to its smoke point as at present. This of itself would not achieve any reduction in smoke emission. Nevertheless, these additives must be regarded as beneficial, if only for the increased flexibility they give in diesel engine design and use.

Apart from additives, unintended changes in fuel characteristics can have some effect on smoke emission but we are satisfied that the ranges of variation that are met in this country have no significant effect on the tendency to produce smoke and that closer fuel specifications would therefore not help.

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(5) Although it is convenient to compare measured levels of pollution with industrial limits, the value of the comparison is limited because the latter are based on 8-hour exposure, a situation rarely met in relation to continuously congested traffic even by professional drivers.

(6) The precipitation of solid or liquid particles suspended in a gas by attracting them to and collecting them on a positively charged electrode.

(7) Devices for separating particles above a specified size from a fluid using centrifugal force (i.e. by imparting a rotating flow to the exhaust gases).

(8) Devices for removing particles from a fluid (in this case exhaust gases) by water washing.

9.4.2 Existing legislation

There is little doubt that diesel engines can, without undue difficulty be designed to operate without producing excessive smoke and are usually so designed. The need is to ensure they continue to be operated in that way. This is a problem of enforcement.

Regulations now require vehicles to be so constructed that no avoidable smoke is emitted and that the excess fuel (cold starting) device be placed where it cannot be used when the vehicle is moving. It is also illegal to use a vehicle which emits smoke that endangers other road users or damages property. Enforcement is not easy because proof of danger, etc., depends on a subjective assessment by the enforcement officer. An increasing number of successful prosecutions is being made and during 1965 13,500 prohibition notices were issued. The result has been a reduction from 9 to 8% in the number of badly smoking vehicles among the total of diesel vehicles observed but with a continually increasing diesel vehicle fleet, this seems to us an inadequate rate of improvement.

9.4.3 Other possible measures

What more could or should be done? Ideal enforcement would require that the smoke from a moving vehicle should be relatable to some objectively specified level. But no instrument is yet available which can fulfil this requirement without fixing it to the vehicle. It is obviously much simpler to carry out the test with the vehicle stationary. At present, the only suitable method is the 'free acceleration' test[9] as used in Belgium and France. We realise this test has deficiencies. The smoke emitted is often less, but occasionally more, than that produced under full load. It may therefore under-estimate the shortcomings of an engine. Conversely, it may give an unfair rating because for example a sudden puff of smoke (which can frequently occur in test conditions) will give a high reading. For this and other reasons it is not always easy to obtain exact consistency between a number of free acceleration smoke measurements. But we do not think these constitute adequate reasons for not fixing maximum acceptable smoke levels under free acceleration conditions. We realise that there are disadvantages, as well as advantages, in adopting arbitrary limits in a field as difficult as this. But several Western European countries already operate such limits and we think they would be a help in this country.

Free acceleration test smoke levels would be of some help to engine manufacturers in deciding on engine ratings and consequent maximum gross vehicle weights. But the shortcomings of the free acceleration test – and particularly the fact that some engines produce more smoke on full load than under free acceleration – mean that an additional standard is required for engine rating.[10] It seems likely that, as a result of the work of the British Standards Institution, a standard[11] will be set for the maximum amount of smoke at the rated maximum horse-power of an engine. If it were possible ultimately to correlate, for particular engines, full load and free acceleration smoke levels, this could further increase the value of free acceleration road-side smoke level tests.

Subjective tests have been made of the levels of vehicle smoke which most people would find acceptable. These showed, not surprisingly, that the smaller the total volume of exhaust gas, the higher the maximum acceptable density of smoke. The results are shown in figure 9:5. Other factors also make it desirable to have separate standards for large and small engines — for example, the smaller the engine, the less margin there generally is between a 'clean' and 'dirty' exhaust. Engines complying with the proposed British Standard should be less liable to emit excessive smoke, but for the future some further improvement will be necessary. We note that the standard is to be reviewed within three years and regard this as an essential step if lower maximum smoke levels are to be achieved. We consider in section 9.7 below the maximum smoke levels that may be desirable.

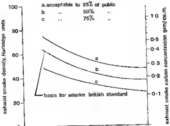


Figure 9:5 Smoke density acceptability ratings

9.5 Pollution from petrol engines

Any excess of fuel over that which is 'chemically correct' increases the amount of carbon monoxide and unburnt or partly burnt hydrocarbons produced by petrol engines. Weaker mixtures increase the production of oxides of nitrogen (but with very weak mixtures the concentration tends to decrease again). Over-rich mixtures are one of the principal causes of carbon monoxide production and occur in many circumstances. The reasons for the use of such mixtures and other causes of pollution from petrol engines are set out in more detail in Appendix 'D'.

Until very recently, the reduction of pollutants from petrol engines was not a significant design objective of any European engine manufacturer but the situation in the USA and the growing realisation that there is also a problem in Europe make it important to assess the prospects for improving the petrol engine.

Pollution can be reduced both by minimising the volume of pollutants resulting from the main combustion process itself and also by getting rid, after that, of such pollutants as are exhausted from the cylinder.

The effect of mixture strength on the level of pollutants and on fuel consumption is shown in figure 9:6. To keep the carbon

(9) In this test, the engine is accelerated rapidly in neutral and the smoke emitted is measured continuously with a smoke-meter. The maximum smoke density measured is taken as an indication of the density likely to be emitted, at some time, on the road.

(10) See glossary.

(11) This will be expressed as weight of carbon per unit volume of exhaust gas. Because of the difficulty of measuring carbon concentrations directly, practical measurements may again be made with a smoke-meter from which carbon levels can be estimated.

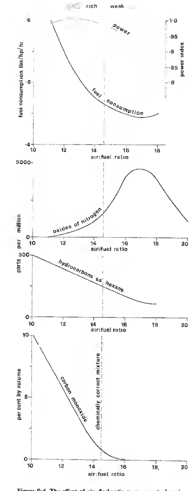


Figure 9:6 The effect of air: fuel ratio on some petrol engine characteristics at maximum rpm

monoxide and hydrocarbon content to a reasonable level would necessitate the air/fuel mixture being not richer than about 14·6:1 by weight (the correct ratio for complete combustion) but even if it were accepted as the desirable objective, the practical attainment of the 'correct' mixture strength under all operating conditions is well-nigh impossible. Such a mixture strength would result in some loss of performance (although it might increase thermal efficiency[12] and improve average fuel consumption slightly). If the rich limit is to be 14·6:1, appreciably weaker mixtures will inevitably occur in some circumstances and the engine must be capable of burning them efficiently.

The ability to burn weaker mixtures is determined largely by the design of the combustion chamber and the condition of the petrol/air mixture entering it. Small engines are generally less able than large engines to burn weak mixtures. At the same time, the high surface-to-volume ratio of the small engine increases the proportion of unburnt hydrocarbons passed to the exhaust. If 'wetness' of the inlet manifold could be avoided, rich accelerating mixtures would be unnecessary and mixture distribution would be improved at the same time. Complete evaporation and mixing may not be achievable but raising the inlet manifold temperature brings an improvement, although higher inlet temperatures reduce power output by lowering the weight of mixture entering the cylinders.

Dilution of the incoming charge by the residual exhaust gases can be minimised by reducing valve overlap to give satisfactory engine idling on weaker mixtures but at the expense of some loss of power at high engine speeds. The emission of hydrocarbons during 'over-run' can be reduced by advancing the ignition and by either avoiding excessive manifold depressions or by cutting off the fuel supply altogether. Retarding the ignition adversely affects power output and fuel consumption but could be an important means of reducing pollutants when the engine is idling.

Carburettors are continually being improved so as to enable them to provide, over the whole operating range, a mixture no richer than that needed for performance and economy. Current developments include closer manufacturing tolerances, and compound carburettors, in conjunction with heated intake manifolds. Some of these give promising results. An alternative approach would be to use a well-designed fuel injection system, which would avoid some of the difficulties of carburation. It would eliminate the over-run problem (because no fuel is injected on over-run) and avoid the problems associated with wetness of the induction manifold, help good atomisation of the fuel and, by overcoming the problem of poor distribution, would make possible the more accurate control of mixture strength in the cylinders. But fuel injection systems are much more expensive and complicated than most existing carburettors and likely to remain so; and their proper maintenance creates problems. Petrol injection is, however, being intensively studied as one of the means of reducing air pollution from vehicles. Insufficient work has been done on both carburation and petrol injection for us to compare the merits of fuel injection with more sophisticated forms of carburation. But we think it important to keep in mind that present carburation systems are simple and cheap compared with fuel injection. If the pollution problem were held to justify the sort of costs involved in fuel injection, it might well be that much improved carburation systems could be developed that would provide a cheaper solution than would ever be possible with fuel injection equipment.

(12) See glossary.

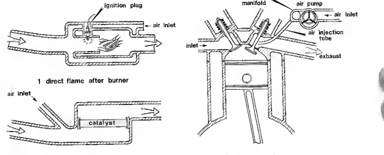
9.5.1 Afterburners

Getting rid of excess carbon monoxide and unburnt hydrocarbons exhausted from the cylinder before they reach the atmosphere can be achieved with some form of 'afterburner'. This can be a direct flame system in the exhaust, a catalytic converter or manifold air oxidation (see figure 9·7). The first two have big disadvantages: they are cumbersome, heavy and expensive and difficult to maintain. The direct flame device needs an ignition plug because it cannot be placed near enough to the engine for the gases to ignite spontaneously. The catalytic device will oxidise the unburnts at a lower temperature but deteriorates in service due to poisoning of the catalyst. A catalytic exhaust device may, however, be a satisfactory way of reducing the oxides of nitrogen when used in conjunction with some other method of removing the hydrocarbons.

Manifold air oxidation is the system favoured by some motor manufacturers. It is a system for injecting air as close as possible to the exhaust valves where the 'unburnts' should be hot enough to ignite immediately and burn. This system is relatively simple and reliable but it requires an air pump, and a distribution manifold. Moreover, the temperature at the exhaust ports must be high enough to ensure that with added oxygen the unburnts are consumed and this may create particular difficulties with small engines.

Up to a quarter of the hydrocarbons emitted reach the atmosphere via the crankcase breather. These emissions can be (and in some cars already are being) dealt with by drawing the 'blow-by' gases out of the crankcase and into the induction system so that the hydrocarbons are burnt in the engine. Although the importance of pollution from hydrocarbons may not at present be very great in this country, the cost of avoiding these emissions from the crankcase is low. We, therefore, think that all new petrol engined vehicles should be equipped so as to prevent crankcase emissions reaching the atmosphere.

Figure 9:7 Alternative after-burners



1 direct flame after burner

2 catalytic converter

3 manifold air oxidation

9.5.2 Fuels

A good deal of work has been done on the possibility of modifying motor spirit to reduce pollution. Although fuel technology may eventually be able to help to reduce hydrocarbon emissions, there seems to be little prospect of altering the composition or finding an additive that will reduce the production of oxides of nitrogen or of carbon monoxide.

We have considered alternative fuels as a means of reducing pollution from petrol engines. The most suitable would probably be a liquid petroleum gas[13] such as propane or butane. These are volatile high octane fuels that would eliminate many of the carburation problems associated with the use of petrol. In this country, no attempt has been made to design for a road vehicle an engine specifically for L.P.G. but with a gas carburettor a normal petrol engine will run on it quite satisfactorily. However, to obtain low levels of exhaust pollutant it would probably be necessary to design engines specifically for L.P.G. fuel. There are two difficulties. L.P.G. has to be stored under pressure; and it is doubtful whether production could be increased to meet a demand commensurate with the general needs of motor vehicles in towns, although sufficient could possibly be supplied for vehicles in a few large towns. In view of these difficulties and the prospect of engines using conventional fuels being made perfectly acceptable for conditions in Britain, it does not seem to us necessary to consider L.P.G. further.

Natural gaseous fuels, such as methane, present different difficulties from those of L.P.G. They have to be stored at very high pressure (as a gas) or at a very low temperature (as a liquid) and in our opinion do not present a practical alternative to motor spirit for personal transport purposes.

9.5.3 Conclusions

The petrol engine is the main contributor to air pollution from motor vehicles in this country and in view of the expected growth in car population, steps need to be taken to reduce the pollution from individual vehicles. We are satisfied that the petrol engine, operating on present fuels, is capable of being designed in a way that would reduce pollutants from it to an extent sufficient to meet conditions in this country.

[13] Liquid petroleum gas (L.P.G.) is a product obtained in refining crude oil.

9.6 Other forms of internal combustion engine

What has been said above applies mainly to piston engines operating on a four-stroke cycle We have considered briefly some other types of engine:

A two-stroke petrol engine is generally a greater contributor to air pollution than a four-stroke of comparable size. Its exhaust gases are more obnoxious and eye-irritating, partly because of the loss of fuel to the exhaust when scavenging[14] and often because in this type of engine lubricating oil is mixed with the fuel. The amount of carbon monoxide from most two-strokes is no less than that from four-stroke engines of similar capacity. Altogether, the problem of reducing pollutants from the two-stroke is likely to be more difficult than it is with the four-stroke engine.

9.6.1 Rotary engines

Very few measurements have been made of the quantity of pollutants from this type of engine but the indications are that the carbon monoxide content will be about the same as that for reciprocating petrol engines of similar size but there may be rather less hydrocarbons But in so far as it may be necessary to mix lubricating oil with the fuel, the rotary engine may suffer some of the same disadvantages as the two-stroke. Pollutants from rotary engines of the 'Wankel' type can probably be reduced by the same methods as in the conventional piston engine

9.6.2 Gas turbines

Few gas turbine engined vehicles have been run on the roads and there is little information about the amount of pollutants emitted. Claims have been made that automotive gas turbines emit virtually none but, even from the few data available, this seems an optimistic view. However, all gas turbines run with considerable excess air (to lower the combustion gas temperature at the turbine blades) and conditions for combustion are good. Experimental work suggests that pollution from carbon monoxide and unburnt hydrocarbons from the gas turbine would probably be better than from the petrol engine but not quite so good as from a well-designed and maintained diesel engine. It would, however, be considerably better than either in respect of oxides of nitrogen, because combustion pressures and temperatures are lower than in the piston engine.

9.7 Possible statutory limits for diesel and petrol engines

We think that the present stage of development of engine design would allow the specifying of maximum levels of smoke from diesel engines, and of carbon monoxide from petrol engines, that would reduce significantly these hazards without creating unacceptable difficulties for manufacturers or operators.

The maximum smoke levels from diesel engines that it may be desirable to lay down in regulations need to take account of many factors, including the levels being adopted by other countries, the scope for improvement in existing vehicles and so on. We have not taken a view of all these factors, but have considered the conditions in the United Kingdom – particularly in towns – and the design and fuel developments open to diesel engine manufacturers and operators in the foreseeable future In the light of these considerations we think that suitable smoke limits, under a free acceleration test and using a light obscuration smoke-meter[15] of the B.P./Hartridge type should be specified. We consider that for this country limits ranging from 65 Hartridge units[16] for engines up to three litres to 45 Hartridge units for engines of seven litres or more represent a desirable target at which to aim. Despite likely increases in the number of diesel engined vehicles in use, the application of these limits for new and existing vehicles would be likely to result in a substantial reduction in diesel smoke

Plate 9-2 Free acceleration test using BP/Hartridge smoke meter

[14] The process by which the cylinders of any internal combustion engine are purged of burnt gases during the exhaust stroke and part of the induction stroke.

[15] A meter which compares the obscuring effect of a column of exhaust smoke with an identical column of clean air by means of a constant light source and a photo-electric cell.

[16] The unit of density on the BP/Hartridge smoke-meter scale. One unit represents 1% of light absorbed (i.e. scale range = 0–100).

For petrol engines, statutory limits will also be needed to secure the improvements required and further research is needed into the relative importance, under British town circumstances, of idling, decelerating and other engine conditions. Pollution limits may also need to take account of other conditions – including traffic speeds – which may change over time. We are well aware that other countries are at various stages in the application of pollution limits to motor vehicles and that these limits may need to be taken into account in deciding what limits might be applied in this country. In the light of all this we do not think it is yet possible to recommend levels of pollutant that might ultimately be appropriate in this country. But in the meantime, we think that present engine design techniques would allow the application of a maximum limit of carbon monoxide emission that could significantly reduce the hazards created by some present levels. Tests on a random selection of British production cars showed carbon monoxide levels in the exhaust, ranging from 2 to 9% when idling and from 1½ to 8% when cruising. One or two cases showed 12 to 14%. Standards that involve test cycles are inevitably difficult to apply and to enforce. There would be great advantages in terms of simplicity in a standard related solely to idling conditions, and since the idling settings of carburettors influence the emission of pollutants under some other conditions, such a standard could provide a worth while check on performance generally. At this stage, without the benefit of the further research needed, the evidence now available suggests that for new vehicles, a maximum level of 3% of carbon monoxide under idling conditions might be considered as an initial objective to be improved upon in due course.

9.8 The effect of vehicle size, traffic density and journey speed on the level of pollution

The level of atmospheric pollution can be reduced by tackling factors other than the amount of pollution from individual engines. The level is affected by vehicle size (the quantity of exhaust gas emitted being roughly proportional to the weight of the vehicle), the number of vehicles, the density of traffic (which affects the proportion of time the engine is idling, accelerating, decelerating or cruising) and the rate at which pollutants are dispersed by air movement. Any forecast of the contribution that these factors might make must be highly speculative but we have attempted to estimate the order of magnitude of possible benefit over a period of a good few years through three factors – improvements in the vehicle design; the use of smaller cars; and freer-flowing traffic conditions. Any such attempt inevitably involves a large number of over-simplifying assumptions, so that the result cannot be regarded as more than a possible indication of the future picture.

It is convenient first to consider the relative rates at which successive sections of a length of roadway are being polluted by carbon monoxide. As an illustration, we have considered the case when three cars stop one after the other at traffic lights, idle, accelerate to 30 mph and run at that speed, and then decelerate for a stop at the next traffic lights 800 feet away, the cycle then being repeated. The result is illustrated in figure 9:8, which shows the highly localised peak just before the traffic lights due to idling levels of carbon monoxide from stationary vehicles. The subsequent acceleration of the vehicles results in an immediate reduction in local pollution because, although the *rate* at which exhaust gas and carbon monoxide are emitted is higher, the *time* the vehicle spends in each successive unit of roadway diminishes as the vehicle gathers speed. When the car attains a uniform speed of 30 mph, there is a reduction in power requirement and pollution, and a further reduction in carbon monoxide occurs when the vehicle decelerates because the throttle is still further closed.

Air turbulence will normally mean that the local peaks of atmospheric pollution will be much less marked than the peaks

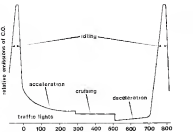


Figure 9:8 Relative emission of carbon monoxide during operating cycle between stops

in the level of vehicle emissions. But figure 9:8 gives an indication of the relative importance, for local levels of pollution, of the levels emitted when idling, accelerating, cruising and decelerating. The general, rather than local, level of pollution in a length of roadway obviously depends on the cycle of idling, acceleration, steady speed and deceleration to which the traffic is subject. Figure 9.9 shows the relative carbon monoxide emissions corresponding to five different cycles – a steady speed of 30 mph; and cycles involving stops that brought the average speeds down to 17·2 mph, 13·2 mph, 8·6 mph and 5·8 mph. The stop-start traffic flow more than doubled the steady running level of pollu-

	% of operating time		
	idling	acceleration/ deceleration	30 m.p.h.
1	60	40	
2	44	56	
3	33	43	24
4	26	34	40
5			100

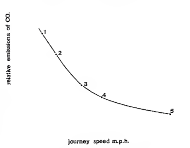


Figure 9:9 Effect of journey speed on relative emissions of carbon monoxide per unit time, per unit length of road-way

tion from each vehicle. This kind of relationship has been shown for actual traffic conditions in the USA.[17]

The increase in carbon monoxide emission of a single vehicle as journey speed is reduced can be used to estimate what happens in a city as traffic density varies. Figure 9:10 shows how mean traffic speed falls as traffic density increases. The relationships

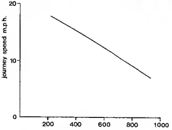


Figure 9:10 Effect of traffic flow on journey speed with 2 intersections/mile

shown in figures 9:9 and 9:10 were used to calculate the relative emissions with various densities of traffic – as indicated by traffic speed – and the results are shown in figure 9:11. This suggests a rapid rise in pollution as traffic speed falls particularly in the range from 0 to 15 mph. Thus there is a four-fold increase in pollution with a halving of traffic speed from 15 to 7½ mph, and a six-fold increase in a traffic jam. Such comparisons are, of course, affected by the assumptions made in regard to exhaust gas composition and figure 9:11 shows the effect on total carbon monoxide emission of halving the idling concentration.

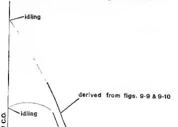


Figure 9:11 Effect of traffic flow on emission of CO per unit time, per unit length of road-way

[17] A. H. Rose, Jr., R. Smith, W. F. McMichael, and R. E. Kruse, *Comparison of Auto Exhaust Emissions from Two Major Cities*, Air Pollution Control Association Annual Meeting, Houston, Texas, June, 1964.

9.9 The scope for reducing overall pollution levels

We consider now the improvement that might be achieved in average pollution levels assuming first no change in the number of cars on city streets.

A reasonable short-term objective would be for the concentration of carbon monoxide in the exhaust of new cars (averaged over the whole driving cycle) to be reduced to half its present value – an *average* reduction. To do this, particular attention would have to be given to reducing the level when idling. Such an improvement, if limited to new cars, would not result in a corresponding halving of actual air pollution for several years. If simple measures could be introduced, and enforced, which would be applicable to used cars, the process of reducing air pollution levels could be speeded up. In any case, it is unlikely that, through this approach, air pollution could be as much as halved in the next five years. A long-term objective could be to reduce the average concentration of carbon monoxide in engine exhausts to about one-third its present level. Such an improvement would need, say, at least ten years to bring about a corresponding improvement in actual air pollution.

We discuss in Chapter 3 the prospects for smaller cars in towns. The engines of such cars would probably emit about one-third the volume of exhaust gas of the present medium-size car and, assuming they emit no higher concentration of carbon monoxide the benefit would clearly be proportional to the number of such cars in use. In the extreme, if the car population – say twenty years hence – consisted entirely of such cars, the amount of carbon monoxide emitted would be reduced to a third through this 'size' factor alone; if only a half were citycars, this reduction would also be halved.

Chapter 3 explains the benefits in terms of traffic flow which would result from a segregated network with no intersections. Such a network would accommodate more cars and would thus increase the number of individual vehicles polluting the atmosphere, but if it were elevated, pollution would be minimised at street level, and moreover substantial benefits would result in terms of a lower level of overall pollution from the regular traffic flow. If instead of the stop-start traffic conditions of the typical town, the network allowed unobstructed movement at a uniform controlled speed of, say, 30 mph, the reduction in the level of overall pollution would be as shown in figure 9:12. While in the two cases there is not much difference between the emissions at low traffic flows, the lower emission with the freeway becomes very significant as the traffic flow increases. The freeway can, of course, accommodate a much greater flow of traffic than the city street (which is near its maximum capacity at the upper end of the curve), but even with a flow of 1,800 vehicles an hour on the freeway, the level of emission would still be a good deal lower than that in a city street with a much smaller traffic flow, crawling along at 7½ mph.

Speculation on the prospects of reducing carbon monoxide air pollution in, say, twenty years, might suggest reductions:

(a) of up to two-thirds of its present level by improvements in engine design;

(b) of up to one-half by a fairly widespread use of citycars;

(c) of up to one-half by improved traffic flow.

As these benefits are cumulative, the overall effect of all these changes could be a reduction to $\frac{1}{12}$th of the present level. Even if traffic flow were trebled in this period, the benefit would still be a reduction to one-quarter of the present level – a very worthwhile improvement. We do not predict that anything like this will happen; we merely suggest these simplified calculations as pointers. And, of course, they do not take into account the further reductions that could come about from more widespread use of small diesel vehicles or of electric propulsion.

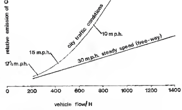


Figure 9:12 Comparison of city and free-way conditions

10 Power Units

The motor vehicle has been made possible by the internal combustion engine which has brought with it the problems of noise and air pollution discussed in Chapters 8 and 9. The ideal engine would occupy little space, weigh little, make no noise and create no pollution. This ideal is, of course, most difficult to attain but we have considered, in the light of this objective, likely trends in power unit developments which might affect the kind of unit available for the very small citycar and, at the other extreme, for the larger bus or goods vehicle.

10.1 Reciprocating internal combustion engines

For cars, motor cycles and light goods vehicles where low cost, low weight, smoothness and mechanical quietness outweigh the need for operating economy, the petrol engine is predominant and its present many good qualities will make it very difficult for any other form of power unit to replace it. For buses and medium to heavy goods vehicles, fuel economy and longer life put the diesel engine in a very strong position. Its fuel consumption is less than two-thirds of that of an equivalent petrol engine and thus has offset its disadvantages of higher cost, greater size and weight and higher noise level. In light goods vehicles, the diesel is becoming more popular particularly for town use, where the proportions of stop-start work and engine idling time are high.

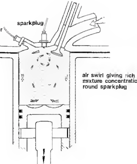
10.1.1 The petrol engine

During the last 20 years the power output and fuel economy of the petrol engine have been improved substantially, through better breathing, manifold design and combustion chamber design, higher engine speeds and higher compression ratios associated with higher quality fuels. These trends will continue but the scope for further improvement is becoming increasingly narrow. For example, the trend towards higher compression ratios will continue much more slowly because of the increased cost of providing higher quality fuels in relation to the diminishing performance advantages. Some further improvement (perhaps 10%) in fuel economy at both full load and part load may be possible, e.g. by using petrol injection to give more uniform distribution, more precise control of the fuel supply and better volumetric efficiency.(1) Power to weight ratios have been improved from about 5·5 lbs/bhp to about 3·3 lbs/bhp in the last thirty years and the extensive use of light alloys could result in a further reduction in engine weight of about a fifth. It seems likely that the petrol engine will retain some weight advantage (perhaps 20–25%) over the diesel engine.

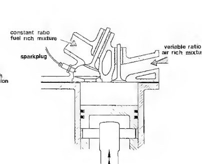
The petrol engine's chief disadvantage is its low efficiency at part load. This could be overcome if power output were controlled by varying the mixture strength instead of by throttling. This is likely to be achievable only by means of stratifying the charge(2) – which could improve the specific fuel consumption under light load conditions by 40% or more. The system is so attractive theoretically that many attempts have been made to achieve it (see figure 10.1) but none have so far become a commercial proposition. Among the possible disadvantages is the risk of producing unpleasant products of partial combustion in certain

(1) The ratio of the actual volume of charge drawn into an engine cylinder during the suction stroke, at normal temperature and pressure (i.e. 0°C and 14·7 lbs/sq in) to the volume swept by the piston.

(2) A stratified charge combustion system provides a local charge of ignitable mixture near the sparking plug instead of a homogeneous mixture throughout the combustion chamber which is necessary on the conventional petrol engine. This makes it possible to vary the amounts of fuel (rather than the amounts of fuel and air) over at least part of the range and economy is not limited by the weak limit of combustion.



Texaco and Witsky engines



Ford engine (Pat.No.948,686)

Figure 10:1 Stratified charge 4 stroke petrol engines

conditions. Further possible developments may be a combination of charge stratification and direct fuel injection, with perhaps the addition of turbo-charging on the larger engines and the use of compound carburettors. But the development work needed on some of these may be overtaken by development of the diesel engine.

Nevertheless, we expect worthwhile improvements in petrol engines which could make them very quiet and almost pollution-free. The petrol engine will, then, probably retain its present supremacy as a power unit for cars, motor cycles and light goods vehicles. It also seems likely to be the most practical and economic power unit for very small specialised town cars of the sort discussed in Chapter 3.

10.1.2 The diesel engine

The basic advantages of the diesel engine are its fuel economy, durability, and very low level of carbon monoxide in the exhaust. It offers considerable potential for development, particularly for large vehicles, the present trend being towards higher power output and lower weight while maintaining or improving fuel consumption and reducing noise.

Power output can be increased by higher engine speed but until now the diesel has been limited to about 4,000 rpm. The use of rotary distributor-type pumps and improved combustion chamber design is now contributing to higher engine speeds and greater power. Until recently, small high speed diesels needed indirect fuel injection systems but further development might now enable direct injection to be used. This should improve fuel consumption of the small diesel by about 10 to 15% but may increase the overall noise, except possibly when idling. At present, it is also more difficult to control smoke emission from small diesels without incurring losses which limit their usefulness. For the future, there is the prospect of small, cheap, high speed diesels with 'pumpless' injection (see figure 10·2) where fuel injection is effected by a pressure difference between a combustion space above the piston and another in the piston crown.

For larger vehicles, the introduction of V6 or V8 engines in the 140 to 250 bhp class is likely to reduce size, weight and cost for the power required. This gain is due partly to the configuration and partly to the ability to use shorter piston strokes which allow

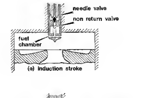


Figure 10:2 Pumpless fuel injection for diesel engines

higher engine speeds and increased power. The penalty may be some increase in fuel consumption and, in some engines, more noise. Possible further developments include manifold-tuning,[3] and turbo-supercharging,[4] which are already beyond the experimental stage.

Turbo-supercharging of both 2- and 4-stroke medium speed heavy duty diesels has shown big gains in power output, but to apply it successfully to lightweight high speed engines may necessitate a new standard of basic engine design. It is unsuitable for conventional petrol engines but could be applied to a fuel injection stratified charge engine. However, supercharging adds complication, makes no contribution to solving the problem of air pollution but may reduce noise or change its character.

For vehicle propulsion, the ideal power unit should deliver at least as much power at low speeds as at high speeds. Present internal combustion engines do not even approach this but engines now being developed seem likely to improve greatly on the performance of present engines. A further development in this direction is the differentially supercharged diesel engine (see figure 10·3) which has a mechanical supercharger driven in such a way that the amount of 'boost' is determined automatically by the torque requirement,[5] rather than the engine or road speed. This can give two-pedal control without some of the disadvantages of conventional automatic transmissions; it also saves size and weight. The principle of differential supercharging has been demonstrated and it may be of considerable importance in improving the performance of goods vehicles and buses. The torque convertor[6] and heat exchanger can also incorporate a hydraulic retarder to provide braking. However, all this brings increased complication and reliability has yet to be proved in service. For the more distant future, diesel compound engines may become practical. In theory they have a lot to offer but it is too early to say whether their advantages can be realised in practice.

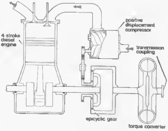


Figure 10:3 Differentially supercharged diesel engine

In total, there is considerable scope for improvement of the diesel engine. Its present disadvantages in size and weight are likely to be reduced a good deal as development progresses. In our opinion it is likely to remain the most suitable power unit for heavy commercial vehicles for very many years and, with further development, might become much more suitable for cars.

10.2 Rotary combustion engines

Widespread application of rotary combustion engines[7] has in the past been prevented by design difficulties that have now been largely overcome by Dr. Felix Wankel (see figure 10·4). Petrol versions of the design are in small-scale production. Compared with a reciprocating piston engine of the same power, the Wankel has low weight, small size, an absence of vibration at speeds above idling, extreme simplicity, low cost, but indifferent fuel consumption. Recent developments show improved fuel consumption, durability and maximum torque at relatively low engine speeds, but many problems remain and it may be ten years or more before the petrol Wankel engine replaces to any marked extent the traditional piston engine. However, some form of rotary combustion engine may well be developed into a suitable power unit for very small cars.

Prospects for diesel versions of the Wankel are far less encouraging. As the compression ratio is raised, the combustion chamber shape becomes progressively less satisfactory and for a given power, the diesel Wankel may show little advantage in size, weight or cost compared with existing small diesels. In the larger sizes, where the gain in size, weight and cost could be considerable, it seems doubtful whether fuel economy or durability would equal that of existing large automotive diesels. Although the rotary diesel should be smoother and quieter than more conventional units the problem of smoke may be more acute. While

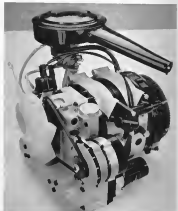


Plate 10-1 Water-cooled 'Wankel' rotary combustion engine

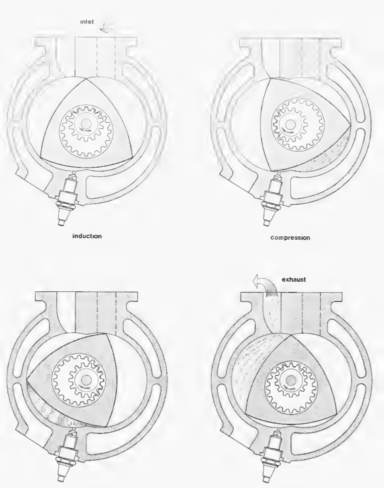
(3) A means of increasing the power output of an engine by matching the pressure pulses in the inlet and exhaust systems and using the optimum length and diameter of induction and exhaust pipes.

(4) The use of an exhaust gas-driven turbine to supply air at above atmospheric pressure to the engine to increase the density of the charge and hence the power output.

(5) The rotating force to be supplied by the engine to propel the vehicle.

(6) A hydraulic device which provides a smoothly variable gear over a limited range as opposed to an orthodox gearbox which provides a small number of fixed ratios.

(7) See glossary.



These diagrams show the sequence of the four stroke principle as related to one face of the rotor assembly. This sequence occurs on all three faces of the rotor simultaneously, giving three power impulses for each complete revolution of the rotor.

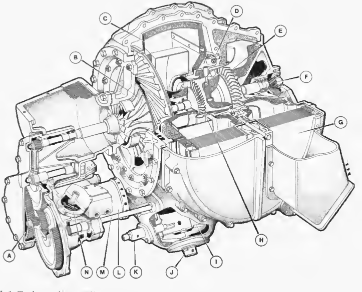
Figure 10:4 Wankel rotary combustion engine

the diesel Wankel cannot [illegible] as a [illegible] unit, we doubt whether it will make much headway against its competitors It is most unlikely to be suitable for very small cars

10.3 Gas turbines

The gas turbine appears attractive as a road vehicle power unit because it offers small size, low weight, absence of vibration, a low level of air pollution, good durability and low maintenance costs. It also has torque characteristics which permit simpler transmission systems, requires no cooling system and has the ability to burn a wide variety of fuels The main disadvantages of the simple gas turbine are its low overall efficiency, heavy fuel consumption at no load and part load, relatively high first cost, slow acceleration and deceleration of the gas generator section and absence of engine braking. Research is being devoted to solving these problems and has led to two-shaft designs (see figure 10 5), (which also provide a built-in torque convertor) The part load fuel consumption of the gas turbine can be improved by a heat exchanger to feed back some of the waste heat from the exhaust into the gas producing section, so that less fuel is needed. In the USA, turbine powered commercial vehicles have already achieved part load specific fuel consumptions better than the petrol engine but still inferior to the diesel. With further development, it would seem that the large gas turbine powered vehicle might be able to achieve a fuel consumption as good as the diesel over the whole range of power output.

The small gas turbine can be adequately silenced and the air intake filtered so that above idling speed the power unit would be



In the Chrysler gas turbine, a variable nozzle system is used to direct the gas on to the blades of the second-stage turbine.

- A accessory drive
- B compressor
- C right-hand regenerator rotor
- D variable nozzle mechanism
- E power turbine
- F reduction gearing
- G left-hand regenerator rotor
- H gas generator turbine
- I burner
- J fuel nozzle
- K igniter
- L starter generator
- M regenerator drive shaft
- N ignition unit

Figure 10:5 Twin shaft regenerative gas turbine (Chrysler A/831)

Plate 10–2 Seven average-sized cars alongside Ford's large gas turbine articulated vehicle

as quiet as a petrol engine and considerably quieter than a diesel. This could become an important advantage in view of the difficulty of keeping the noise from more powerful diesel engines down to an acceptable level.

Whatever line of future development is followed, the result is likely to be an increase in the complexity, weight and cost of a practical vehicle gas turbine and the basic materials needed for the engine are inherently more costly than those used in piston engines. Taking account of all this, and although a number of large gas turbine cars are under development, we doubt whether this type of power unit could be developed to a point where it would be both practical and economic for small cars.

However, as the size and performance of commercial vehicles increases and engines of 250 to 400 bhp become necessary, the gas turbine may then prove superior to any other form of power unit for large goods vehicles and perhaps long distance coaches. But we consider that it will be at least ten years before gas turbines are likely to be made available on production vehicles of this kind.

10.4 Air cycle engines

In the past, the need for scarce and expensive materials capable of withstanding very high temperatures seriously hindered development of the air cycle engine[8] but this type of power unit has recently become more practicable due to modern metallurgical and engineering techniques. Current designs are now being developed for automotive use but they are not yet advanced enough for their probable performance to be assessed. They may, however, have some distinct advantages, including very high thermal efficiency, good low speed torque, silent operation and ability to use a wide variety of liquid and solid fuels. Also, as precise control of combustion can be maintained the 'exhaust' should cause the minimum of air pollution. But air cycle engines tend to be mechanically complicated, need exotic materials and are expensive. Their efficiency depends to a large extent on the design of regenerator[9] which may require considerable development before it is satisfactory. Moreover, normal methods of power control are impracticable and the proposed methods make use of variable compression and engine reversibility which have yet to be demonstrated. In practice, the size, weight and overall efficiency of the air cycle engine seem likely to be similar to that of an equivalent diesel engine but the wide torque range may make a multi-speed transmission unnecessary. However, in spite of its advantages we do not think there is much prospect of the air cycle engine becoming competitive with the internal combustion engine within the time-scale we are considering.

10.5 Battery electric traction

There are a number of possible alternatives to the internal combustion engine, including stored energy in the form of, for example, re-chargeable electric batteries, compressed air, steam, or kinetic energy in a flywheel rotating initially at high speed. Of these, the electric battery has the decisive advantage that it delivers up its stored energy at virtually constant potential. In spite of its weight, the lead-acid battery is the most efficient method of storing energy that is at present in large scale com-

(8) The air cycle engine, like the steam engine, is an external combustion engine. Heat is supplied to the working fluid (usually an inert gas such as helium) through the cylinder walls from an outside source. The basic cycle depends on expansion and contraction of the gas, which is completely sealed inside the engine and used continuously. The gas drives a power piston and a displacer piston which work in a single cylinder. These pistons move the gas through a heating-regenerating-cooling cycle which approaches the theoretical maximum (Carnot) efficiency for any heat engine.

(9) A device which can alternately store or supply heat in a (theoretically) reversible manner.

mercial use. We have, therefore, used it as the standard of comparison both when discussing the relative merits of electric propulsion and the internal combustion engine, and when considering other systems and possible developments in storage batteries.

Battery electric cars, taxis, buses and goods vehicles enjoyed brief popularity at the turn of the last century but with the rapid development of the internal combustion engine they could not continue to compete on capital cost, performance or range and battery electric traction is now used only for a few types of local delivery vans and trucks and material handling vehicles inside factories. The low energy to weight ratio of lead-acid batteries virtually precludes them from ever becoming a power source for longer distance travel. But within towns, where limited speed, acceleration and range are not so important electric vehicles seem an obvious solution to the problems of pollution and noise. They offer freedom from exhaust fumes, low levels of external and internal noise, 2-pedal control and low running costs. We have, therefore, examined the prospects for battery electric town vehicles. We have done this in conjunction with the Electricity Council and some vehicle and component manufacturers.

Until recently, there has been little effort, or incentive, to produce battery electric cars, so that there is not much practical data from which to assess their likely performance. But recently several converted petrol engined cars and specially designed prototypes have been demonstrated. The conversions are essentially research vehicles for the evaluation of techniques and systems; as the Electricity Council point out, the electric car will have to be 'purpose-built' if it is to be successful. These experimental vehicles use conventional lead-acid batteries, series wound direct current motors and carbon pile(10) or electronic 'pulse' controllers. They achieved speeds and accelerations much better than those of the battery electric delivery truck but, in our opinion, are still not quite good enough to make them an acceptable alternative to the petrol engined car. Above all, their limited range and excessive weight remain serious problems.

It is convenient to consider separately the prospects for motors, controllers, batteries and chargers.

10.5.1 Motors

The characteristics of conventional series wound direct current motors are well suited to traction. However, they can produce much greater torque than is needed for normal duty and smooth control is necessary to avoid jerks, particularly when starting from rest. The maximum efficiency of traction motors is about 85% but the average efficiency is only about 60% when the vehicle is used in traffic and the scope for improvement seems slight. The power to weight ratio of traction motors is generally poor (about 6–10 lbs per bhp) but recently 3 lbs per bhp has been achieved experimentally. Further improvement seems possible with high-speed lightweight blower-cooled motors. For the future, induction or brushless direct current motors may achieve higher efficiencies and power to weight ratios of 1 lb bhp seem feasible. Brushless D.C. motors lend themselves to regenerative braking.(11)

10.5.2 Controllers

The simplest control is stepped resistors in series with the motor. This accelerates the vehicle in jerks and results in up to a quarter of the battery capacity being wasted heating the controller. The use of a 'stepless' carbon pile controller eliminates the jerks but not the losses. Both types of controller are heavy. Parallel series battery control can help reduce the losses and thereby increase range by 10 to 15%. More recently, semi-conductor methods of control through silicon controlled rectifiers have been applied to battery electric vehicles. These give 'loss-free' as well as stepless control, thus providing a continuously variable speed, together

Plate 10–3 Battery-electric articulated milk float

Plate 10–4 The 'Scamp' – purpose-built electric car, designed by Scottish Aviation Ltd.

(10) A controller consisting of a stack of carbon discs, the resistance of which can be varied by external pressure thereby regulating the voltage applied to an electric motor so as to give smooth changes of speed.

(11) See glossary.

with regenerative braking which can increase range by about 10%. At present electronic controllers are, however, more complicated and expensive than other forms of control, are rather heavy (about 100 lbs) and noisy. The gain from the use of more sophisticated controllers becomes important under stop-start in slow moving traffic and in hilly terrain. Research is, therefore, being devoted to the development of lighter, cheaper and more efficient controllers.

10.5.3 Batteries

The energy to weight ratio of the battery determines the performance of an electric vehicle. Not only are good acceleration, hill-climbing ability and high top speed obtainable only at the cost of some loss of range, but the energy to weight ratio of present batteries puts an early limit on the total performance now possible from an electric vehicle. For example, the batteries in one of the experimental cars sponsored by the Electricity Council weighed 830 lbs, provided a top speed of 40 mph, an acceleration of 4 mph per second up to 20 mph and a non-stop range of about 30 miles on level ground. The weight of batteries might, with development, be reduced to perhaps 600 lbs. This would improve performance a little. The outstanding need is for a battery with a much higher energy to weight ratio but this is unlikely to be achieved with the lead-acid battery.

In addition to a high energy to weight ratio, batteries for vehicle propulsion need a long life in terms of charge and discharge cycles, the ability to accept a rapid re-charging (present batteries need 5 to 10 hours for re-charging) and low cost. No battery at present available meets these further needs. Lead-acid and nickel-iron batteries are capable of delivering only about 8 to 12 watt-hours per lb. Nickel-cadmium, silver-cadmium and silver-zinc batteries are all expensive, as well as having other disadvantages.

The main object of present battery research is to increase the energy to weight ratio. Fuel cell research has led to the development of air electrodes, making possible the zinc-air battery which has a very high theoretical energy to weight ratio. Experimental zinc-air batteries built by the General Dynamics Corporation in the USA have achieved energy densities of 50 to 60 watt-hours per lb. and even higher ratings may be possible. Table 10·1 shows some of the advantages of a zinc-air system compared with other batteries.

Battery Type	Active Material	Approx. Price (£ per ton)	Energy Density: Theoretical (watthrs per lb)	Energy Density: Achieved (watthrs per lb)	Energy Density: Achieved (watthrs per cu. in)
Lead-acid	Lead	100	115	12	0·9
Nickel-iron	Nickel	650	215	11	0·8
Zinc-silver	Silver	15,000	220	40–70	2·5–3·5
Zinc-air	Zinc	100	400	50–60*	2·0–3·0*
Cadmium-air	Cadmium	1,800	500	25–35†	—

*Data based on detailed design study.
†Estimated.

Table 10:1 Theoretical and achieved energy densities of motive power battery systems

In the zinc-air battery, zinc plates form one electrode, porous nickel plates the other; the electrolyte is a solution of potassium hydroxide. The energy release occurs as a result of the conversion of zinc to zinc oxide. Air for this purpose is pumped through the porous nickel plates and oxidization occurs when the air reaches the zinc anode. The electrolyte is passed through the cell stack, carries the zinc oxide to a filter and then goes on to a reservoir

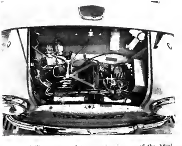


Plate 10–5 The motor and transmission in one of the Mini-Travellers converted for the Electricity Council by Telearchics Ltd

Plate 10–6 The batteries in the Mini-Traveller converted for the Electricity Council by A.E.I. Ltd

(see figure 10:6). Storage of the reaction products outside the cell avoids their build-up on the plates, impeding the reaction, as happens in lead-acid batteries. The battery can be charged in the normal way.

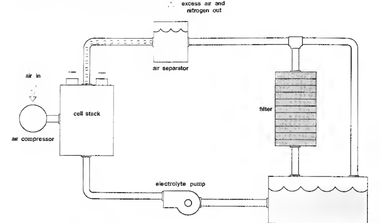


Figure 10:6 Simplified schematic flow diagram for zinc-air battery

However, the zinc-air battery needs an air compressor, a pump for circulating the electrolyte, a filter, a storage tank and an air separator in addition to the cells. It is more complicated and likely to be more costly than a lead-acid battery of similar capacity. Some further technical problems remain to be overcome and it seems likely that it will be at least five years before such battery systems become a commercial proposition in this country. An indication of the increase in range which might be obtained from a zinc-air battery is given in Table 10:2.

Battery Rating (watt hrs/lb)	Battery Weight (lbs)	Energy Capacity (kw hr)	Approx. Range (miles)
12 (lead-acid)	850	10	35–45
50 (zinc-air)	850	42·5	150–200
50 (zinc-air)	500	25	80–120

Table 10:2 Range of typical vehicle (3,000 lb gross weight)

10.5.4 Battery chargers

The charging equipment for battery electric vans and trucks is not usually carried on the vehicle but for an electric car to have a built-in charger would increase its flexibility and help compensate for its short range. Present battery chargers cost about £50 and weigh about 80 lbs. We have seen no indication of the prospects for big reductions in cost, weight or size. The need for built-in chargers would be less if batteries providing a much improved range become available.

10.5.5 General considerations

Considerable further development is needed if battery electric cars are to become generally accepted as a practical alternative to the petrol engined car. Although electric cars could probably meet most of the performance requirements for a small town vehicle as set out in section 3.5.6 of Chapter 3 and also have very good stability, their limited range, although enough for a high proportion of town trips, would be a serious inconvenience. In congested traffic or in hilly districts the range is likely to be a good deal less than that obtained running free on the level. And a discharged battery cannot be refilled quickly, like a petrol tank. The effective range is therefore likely to remain the critical factor until batteries with a considerably higher energy to weight ratio become available.

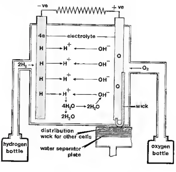
Other methods could help to increase the range of an electric vehicle – such as the provision of charging facilities at parking meters, off-street vehicle parks and garages. Vehicles might be designed so that the batteries could be replaced easily as a unit. This would, however, need a completely different pattern of operation, with spare batteries being held at convenient exchange points. Standardised equipment would be needed and we think that the cost and difficulty of providing such a service might make it impracticable.

Although it is possible that the first cost of a specially designed vehicle could be lower than that of a similar petrol engined car, and 'fuel' and maintenance costs are also low, the cost of battery replacement every four years is high. Many people might find it difficult to set aside up to £150 for this and special arrangements might have to be made for batteries to be hired. This particular problem would not necessarily be overcome simply by an improved battery energy to weight ratio.

10.6 Fuel cells

Fuel cells convert fuel into electric power, which can be used to drive motors or other electrical equipment. Their essential feature is that the material needed to generate the electric power are fed in continuously, while the reaction products are continuously removed, the cells remaining largely unaltered. This differentiates them from the ordinary primary or secondary battery, in which the electrodes are either consumed, or subjected to chemical changes which are then reversed by a recharging process.

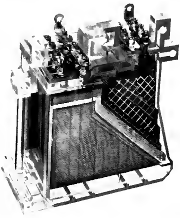
Figure 10:7 Diagrammatic representation of a hydrogen-oxygen fuel cell



Fuel cells are not in general industrial use but their recent successful application in space satellites has helped to draw attention again to their possible use for other forms of transport. The potential absence of noise and fumes from a power system based on a fuel cell and electric motor has led to suggestions that they might provide particular advantages for town transport vehicles. But the fuel cell seems a long way from any industrial application and perhaps further still from use in a road vehicle, and particularly a small car. We have looked briefly at the possible forms of fuel cell known today and their possible application for road vehicle use.

The chemical reactions in a fuel cell rely on oxidization of a fuel. To generate electricity from this requires that the fuel and oxidizer are supplied to two different electrodes that are linked, within the cell, by the electrolyte. A simple application of this uses hydrogen as the fuel, oxygen as the oxidant and potassium hydroxide as the electrolyte (see figure 10:7). This can produce electricity so long as the hydrogen and oxygen supplies are maintained; the reaction produces only water as a by-product. The basic problem in the practical development of a fuel cell is in bringing together the solid electrode material from which the electric power can be collected, the liquid electrolyte that forms the internal electrical circuit and the gas that provides the fuel or oxidant. Practical fuel cell designs represent different ways of tackling this problem. They can conveniently be grouped according to the temperature at which they operate – low temperature cells, up to about 100°C; medium temperature cells, at 150° to 350°C; and high temperature cells, at 400° to 1,000°C.

Plate 10–7 A sectioned hydrogen-oxygen fuel cell by Electrical Power Storage Ltd



Low temperature cells can operate on hydrogen gas as fuel, oxygen or air as the oxidizer but need a catalyst (usually involving platinum) incorporated into the electrodes. To avoid the difficulties of supplying hydrogen as a gas, it is possible to use hydrazine ($N_2H_4.H_2O$) as the fuel, but as hydrazine is both very toxic and at present expensive, it is unsuitable for general use in vehicles. Alternatively, methanol can be used as the hydrogen source but to react at normal temperatures this requires a very expensive catalyst – perhaps £150 worth of platinum for each horse-power of electrical energy.

The medium temperature cell can avoid the high-cost catalysts, because less rare materials, such as nickel, will then operate as catalysts. Alternatively, the combination of medium temperature and platinum as a catalyst makes possible a cell using propane as a fuel.

Hydrocarbons provide a very convenient form of fuel for vehicles, but to oxidise a wide range of them with the catalysts at present available may need high temperatures. These create corrosion and engineering problems (including the use of auxiliary equipment) that increase cost and reduce suitability for the sort of small-scale installations that would be needed in a car.

The fuel cell could have a theoretical efficiency, in converting fuel into electrical energy, approaching 100%. But electrical losses within the cell, the power used by auxiliaries and, in high temperature cells, the heat losses, might mean practical efficiencies of the order of 40%. It might thus still be nearly twice as efficient as a petrol engine but for vehicle – and particularly car – use, this gain is of little importance so long as the real cost of fuel remains a very small proportion of the total real costs of vehicle use and if the first cost of the power unit is substantially higher. The power to weight ratio of a fuel cell system does not seem likely to offer much advantage over an internal combustion engine.

Major difficulties stand in the way of the use of fuel cells in road vehicles. Hydrogen provides the best fuel but the cost, weight penalty and danger of storing and using it in gaseous form make it quite unsuitable for general mobile use. To use methanol or a hydrocarbon as the hydrogen source needs, at present, a prohibitively expensive catalyst or temperatures so high as to make the system quite unsuitable for small installations or for providing power quickly from cold. But a great deal of effort is now being put into fuel cell research – not primarily for road vehicle use – and this may well produce results relevant to road vehicles. Solving the engineering problems connected with high temperature systems using petroleum fuels might possibly create a power source suitable for road vehicles that were in comparatively continuous use – such as buses, coaches or lorries. The absence of vibration and low level of noise potentially obtainable might have passenger appeal. For car use, the essential need is for a cheap catalyst that would make possible a low temperature (say, below 100°C) reaction with fuels of a sort that could safely be used in large numbers of privately-owned vehicles. This is not the sort of objective that can be achieved merely by more development effort. It would be, in popular terms, something of a 'breakthrough', assessing the possibility of which we regard as speculation. While, therefore, unforeseeable developments could make the fuel cell a practical proposition for road vehicles and even for cars, the state of fuel cell technology at the moment leaves some major difficulties in the way of extensive industrial use of fuel cells; and these difficulties are even more acute in the application of fuel cells to road vehicles.[12]

10.7 Atomic power sources

Atomic power requires shielding. In the absence of some completely new form of shielding, much lighter and yet at least as effective as existing materials, we do not consider atomic reactors or radio-active isotopes worthy of serious consideration as power sources for road vehicles, and particularly for small vehicles.

10.8 Conclusions

Unforeseen developments in power units are always possible. But on the basis of what is at present foreseeable we consider that the reciprocating or perhaps the rotary internal combustion engine will remain for many years the best form of power unit for road vehicles generally and particularly for small citycars. Very large commercial vehicles will continue to present a noise problem but for other vehicles, noise need present no serious difficulties and air pollution, under British conditions, could be reduced to insignificant proportions. But the zinc-air battery may well prove to be a major development. The need for its auxiliary equipment means that very small installations may be comparatively expensive and may therefore prove more attractive in the sort of size that would be needed for small buses or goods vehicles. Its potentially noiseless and fumeless characteristics could make it particularly well suited to some town applications. At present, battery electric vehicles cannot combine adequate acceleration, speed – particularly on hills – and above all, range. But with the development of practical and economic storage systems having four to five times the energy to weight ratio of the lead-acid battery they might become by far the most promising alternative to the internal combustion engine for town vehicles.

[12] Experimental Sodium-sulphur-alumina and Lithium-chlorine 'molten metal' cells are now being developed for vehicle use by Ford and General Motors respectively. In both cases, the performance claimed is much superior to that of the lead-acid battery but as the Sodium-sulphur cell operates at 250 to 300°C and the Lithium-chlorine cell at 315 to 650°C, there are many practical problems still to be solved.

11 Automatic vehicle control

It is characteristic of the motor vehicle of today that its motion is fully controlled by the individual driver. He has to monitor its position, speed, acceleration or deceleration in relation to the desired route, surrounding traffic and fixed obstacles. He must also react to road signs and signals, and ignore distractions. From what he sees and senses he decides how to operate the vehicle controls. The human brain and sensory system perform these functions with remarkable skill and reliability, but they do so comparatively slowly in relation to the speed of events in moving traffic. For example, there is usually a delay of about one second between a driver first seeing a hazard and being able to initiate consequential action. Most of this time is taken up by the driver in observing the situation, deciding upon the action required, and making the necessary body movements to operate the controls. By using automatic devices rather than relying on the driver it might be possible to reduce this time lag and also the risk of errors. This could have two advantages. Road capacity might be increased, and road safety might be improved. In bad visibility a system providing better observation than the human eye would be particularly valuable.

But automatic control has a most important limitation. The system would have to respond more quickly than the average driver, or there would be little benefit from it. It follows that if it failed, the driver would be unable to take over at the instant of failure. Consequently, the system would not only need to be reliable; it would also have to create a safe situation if it broke down – and merely bringing the vehicle to a halt might not be a particularly appropriate action. We can find no present-day parallel for a system in which the person in charge and at risk cannot take over from an automatic mechanism in an emergency.[1] Furthermore, some experiments with automatic vehicle control have suggested that a system which did not perform better than the driver thought he could do himself, would not be acceptable to the ordinary man-in-the-car. The psychological as well as the safety aspects of automatic vehicle control would therefore need thorough investigation before any system could be brought into everyday use.

11.1 The possibilities

The ultimate in de-personalized control would be fully automated door-to-door travel, with automatic route-ing. Although this may be on the threshold of technical feasibility, we think that its practical application is beyond our time-scale, and the operational, administrative and economic questions it raises are beyond the scope of this study. Systems have been devised for linking road vehicles together to make part of the journey on fixed tracks.[2] This raises a wide range of considerations that we have not gone into because we see the concept as being somewhat outside our terms of reference. Warning devices and conventional vehicle controls might also be improved, but we regard these as aids to driving, and have dealt with them in Chapter 7.

In this chapter we have therefore limited ourselves to considering:

(a) automatic steering, or *vehicle guidance*; and

(b) automatic spacing, or *proximity control*.

We have mainly considered the use of these controls in town traffic, although they may well have uses on inter-urban roads, especially motorways. We have not considered automatic speed control as such. Systems have already been developed which enable a desired cruising speed to be maintained automatically. Although speed control could form part of, for example, a system for controlling traffic flows over a wide area, it seems to us that, at any rate for town traffic, it must be considered as part of the process of proximity control.

11.2 Vehicle guidance

We see the main purpose of vehicle guidance in towns as being to enable vehicles to be driven safely in very narrow traffic lanes. This would be particularly valuable with vehicles of fairly uniform width. It could be particularly important in contributing to the safety of an overhead road system such as is described in Chapter 3. Guidance systems might also improve safety in fog, and guard against errors resulting from tiredness or inattention.

In Chapter 2 we suggested that at present a lateral spacing of about 2 ft 6 in to 3 ft is needed between cars at normal town traffic speeds. If this distance could be halved with no loss of safety, it would enable lane widths to be reduced by about 15% for present-day average-sized cars and by more than 20% for the smaller citycars we have considered. It might also make it possible for wide commercial vehicles and buses to operate safely at speed on traffic lanes much narrower than the standard 12 ft width now aimed at. This could make it possible to create additional traffic lanes within existing road widths, with consequent advantages in the better use of road space and some savings in highway costs.

The simplest form of vehicle guidance is a guide rail of some kind. A mechanical guidance system is used on part of the Paris 'metro', and various systems using horizontal wheels to guide vehicles between side rails, or astride a central rail, have been developed experimentally. These systems may have applications for special purposes, such as for buses operating on reserved tracks, or perhaps for small vehicles on the kind of segregated system described in Chapter 3. But the rails usually have to be above ground, and we think that the difficulties this creates at intersections and in overtaking seriously restricts the general usefulness of such systems.

Various other means of guidance are possible. Essentially, they require a trail to be laid which can be detected by a device on the vehicle. The trail might, for example, be a painted line, followed optically, or a radio-active or metallic strip, detected electro-magnetically.[3] A system using a cable carrying an electric

(1) Automatic take-off and landing systems for aircraft are not in the same category. The situations are not comparable, the number of installations is comparatively few and because of the advantages such systems offer to airline operation, high cost does not necessarily rule them out. Moreover, the operators are carefully selected and highly trained.

(2) Such as the StaRRcar system being developed by Alden Self-Transit Systems Corporation in USA.

(3) i.e. by a system using radio waves.

Plate 11–1 Mechanical guidance system used on Montreal Metro

Plate 11–2 'Hands-off' driving at the Road Research Laboratory

current which can be detected by coils mounted on the vehicle has been developed experimentally by the Road Research Laboratory and enables a car to be driven 'hands-off' at 40 mph with no significant deviation either side of the centre line. The cable is easily laid in a groove sawn in the road surface, and requires very little power (see figure 11:1). The normal car battery can provide the power needed for the vehicle equipment. A system on similar principles has also been developed by General Motors Research Laboratories. Ordinary manual control is possible for overtaking, for selecting a route at a junction or for use on roads without guidance control. It appears to be comparatively simple to incorporate manual over-ride facilities in non-mechanical systems, and this seems to offer great advantages over mechanical guidance.

We conclude that guidance systems in one form or another are feasible and could in suitable circumstances be used to reduce lane widths. Whether guidance would bring about an overall improvement in road safety is less clear. Unless it was combined with proximity control, obstacles on the guide path might be a hazard, and pedestrians crossing roads might be at greater risk than they are now. At present, a simple electrical system appears to be the most promising for early development. But on ordinary multi-purpose streets vehicles need to be able to stop, change lanes and turn off at intersections. Under these conditions automatic guidance seems unlikely to increase road capacity to any worthwhile extent, and we are not sure that it would make any very great contribution to road safety, except in bad visibility. We do, however, see scope for the use of some system of this kind for buses especially if they were to be operated on reserved lanes. They are of fairly uniform width and performance, and follow defined routes. The number of buses to be equipped would be small, as compared with the total vehicle population. Bus passengers and other road users might all benefit if buses could use, on at least part of their routes, narrower lanes than they do at present. Whether the savings obtainable by a particular system would justify its cost is another matter, and one that would need to be evaluated.

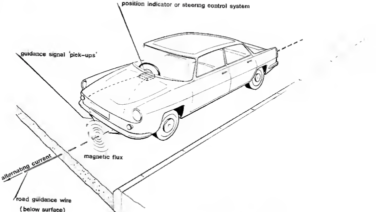


Figure 11:1 A simplified guidance system

Plate 11–3 E.M.I. Robotug driverless truck system in action

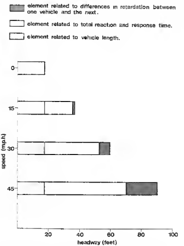


Figure 11:2 Changes in the make-up of vehicle headway as speed increases

Outside towns, a guidance system might well have applications in relieving the driver of part of his task, although manoeuvres such as overtaking and passing stationary obstacles would create problems of interchange between automatic and manual control which do not appear so far to have been satisfactorily resolved.

11.3 Proximity control

We showed in Chapter 2 that driver reaction time is an important factor in the amount of road space needed by a vehicle in moving traffic. The comparison of the make-up of beadways in figure 11 2 shows that at speeds of more than 15 mph the greater part of headway consists of the distance allowed by drivers for the time they and their vehicles need to react to the behaviour of traffic ahead.

In clear weather a driver can usually see further ahead than the next vehicle, and can anticipate the action he is likely to have to take. Even so, if a driver's response time could be eliminated, we estimate that a 40% increase in lane capacity could theoretically be obtained using present-day, average-sized cars; and the margin of safety would be greater than at present. When combined with automatic guidance, the increase in capacity obtainable from proximity control could be even greater. We recognise that this is an over-simplification of the town traffic situation, where the main limitations on the capacity of urban roads are the bottlenecks caused by intersections. But the main factor affecting vehicle spacing through light-controlled intersections is the time-lag in moving off. Here, too, proximity control could increase traffic capacity.

The problems of proximity control are much more complex than those of automatic guidance. Keeping correct station behind a moving vehicle entails continuously observing its performance and perhaps the behaviour of traffic further ahead, and adjusting the speed of the controlled vehicle. Research into possible ways of eliminating human fallibility and response time has followed two lines:

(a) control from the roadside; and

(b) control within the vehicle.

11.3.1 Control from the roadside

Control from the roadside is analogous to railway automatic train control. The road is divided into sections and the behaviour of vehicles passing through each section is continuously monitored. The appropriate speeds for vehicles following in other sections are calculated by computer and controlled automatically from the roadside. A system of this type, combined with guidance, has been developed to demonstration model stage by General Motors Research Laboratories.(4)

11.3.2 Control within the vehicle

To equip each vehicle with an 'automatic driver' is more difficult. The problem is to devise a detector as discerning as the human eye and a computer capable of making the same kind of decision as the human brain. A good deal of theoretical work has since been done on this(5) and mathematical solutions have been suggested but, so far as we are aware, these studies have not reached the stage of practical experiment.

(4) General Motors Research Laboratories Auto-Control System – described in U.S. Highway Research Board Bulletin 261 (1960), Electronic Highways.

(5) For example, by R. L. Cosgriff, J. J. English and W. B. Roeca at Ohio State University

An effective system would need:

(a) to be capable of maintaining a steady time interval between vehicles, appreciably shorter than that which can safely be maintained by the average human driver;

(b) to produce smooth acceleration and deceleration in the controlled vehicle; and

(c) to prevent minor changes in speed and interval at the head of a group of vehicles from becoming accentuated further down the line.

The information needed for automatically controlling the spacing between a vehicle and the one in front includes:

(a) the distance to the vehicle ahead,

(b) the relative speed of the controlled vehicle to it, and

(c) the rate of acceleration or deceleration of the controlled vehicle.

To obtain this it is essential to measure, at very short intervals of time, the distance to the vehicle next ahead. Of the many ways in which this might be done, the most promising, but not necessarily the only practical way,[6] appears at present to be with a miniaturised radar system, using one of the recently developed microwave sources. A major problem, as with any other system relying on reflection, is to discriminate between the echoes returned from the vehicle ahead and other objects or vehicles. This might be coped with by fitting secondary radar systems to the rear of all vehicles, as well as transmitters and receivers to the front. Electronic manufacturing techniques are developing very rapidly, and the mass production of very small, reliable and cheap radar equipment may well be possible within the time-scale we are considering. But we must emphasise that this is only one part of the problem. The assessment of the measurements obtained remains a formidable computer problem, and a servo system[7] would be needed to operate the vehicle controls. The system would have to be considered as a whole, and new systems of controlling the engine, transmission and brakes might be needed.

Even if the basic technology is possible, a lot of problems remain. Vehicles would follow one another at no more, and no less, than the minimum safe interval. The driver could not safely be allowed to over-ride the automatic control. Situations such as merging traffic streams, passing stationary vehicles, and leaving the traffic stream would pose great difficulties. Means would need to be found for dealing with changes in road conditions, such as icing, and perhaps for such variables as the efficiency of braking systems. Unless and until the system were fitted to all vehicles, drivers would need to learn, and to be constantly aware, that there were some occasions when they could rely on this system and others when they could not. There would be a considerable risk that automatic control would condition drivers to travelling at intervals that would be unsafe with manual control. We, therefore, have serious reservations about the practicability of any system of proximity control short of complete automation, which is a much more remote possibility than anything we have considered here.

11.4 Conclusions

Automatic guidance is already technically possible. Electronic rather than mechanical means appear to hold the most promise, except possibly for very specialised applications. Under town conditions, the early benefits obtainable from automatic guidance may be in bus operation, where it could offer the space saving advantages of a fixed track system whilst retaining the flexibility of the bus in picking-up and setting-down areas, and at depots.

Although methods of controlling vehicles from the roadside have been developed to quite an advanced stage, they are more suited to motorways than to typical town street conditions in this country, and satisfactory solutions do not yet appear to have been found to the problems associated with passing, the mixing of controlled and uncontrolled vehicles, and safety in the event of equipment failure.

We are very doubtful about the possibilities for fitting each vehicle with its own proximity control system. It seems likely that it could not in any event, be entirely self-contained. Whilst most of the technology may be possible within our time-scale, there would be very great difficulties in applying it to actual road conditions. A high degree of reliability and built-in safety would be essential; even so, it would create unprecedented problems of driver psychology. Assuming that a proximity control system could be perfected, the manufacture, installation and maintenance of the equipment needed for even the simplest system would, inevitably, cost a great deal in money and technological resources, and this would need to be weighed against any saving in expenditure on highway construction or other traffic facilities that the system might make possible. We consider that it would first of all be necessary to develop experimental systems in order to evaluate whether the gains would be likely to justify the cost, as well as to test human reactions to it. As we have suggested in Chapter 7 we think that a more immediate and worthwhile application of the detector systems needed for proximity control might be in a warning device that would enable vehicles to operate on motorways and other high-speed roads in bad visibility without the risk of multiple shunt collisions.

[6] Infra-red and ultra-sonic means have, for example, been suggested, and we are informed that some experiments have been made with the latter.

[7] See glossary.

12 The future context

In this study we have particularly sought to establish how the community could make extensive use of cars, as it evidently wishes, while at the same time reducing as much as possible the difficulties and penalties that this creates for society at the present time We think this emphasis on the car is right, for two reasons First, in setting up the study, the then Minister of Transport made it clear that it was coping with the private car, rather than other sorts of vehicles, that was particularly difficult Second, we think that in the decades ahead many more people are going to be able to afford, and are going to expect, higher standards of personal comfort and convenience And in the field of transport, this seems to us likely to take the form of a desire, by society as a whole, to make increasing use of the car.

Our analysis of the vehicle design features that would make possible greater use of the car led inevitably to our looking at the broad traffic circumstances in which cars operate, the space savings from segregation of cars and the possible need for some new road works to achieve such segregation Some cities in the USA have shown the degree of motorized mobility that is possible by planning urban development around the use of the car and by devoting considerable resources, of both land and material, to road building We have taken it as axiomatic that this option is not open to us in this country, not only will land in our towns always be scarce but manpower and materials available for road building will also be limited So although more money is now being invested in roads in towns, we doubt if potential demand for urban road space can ever be fully met We have, therefore, assumed that there will remain a pressing need to get the best

Plate 12-1 Motorised mobility at a price

Plate 12–2 Severance of communities by general purpose motorways

value out of space and money We think our study shows one way in which a lot more personal motorized mobility could be achieved without the penalty of the space needs and cost of all-purpose urban motorways

It often appears that improvements in the capacity of a road system are very quickly matched by such an increase in traffic that much of the potential benefit from the increased capacity seems lost It might be argued that this will inevitably apply to any attempts to increase accessibility by car But it seems to us that this ignores two factors First, even if increased capacity is largely taken up by increased traffic, it still allows a greater number of people the benefit of the use of personal transport. Second, there seems to be an increasing recognition that some means must be found to ensure that traffic congestion itself does not indefinitely continue to be the main factor limiting the growth of traffic If other methods – from simply a more comprehensive policy towards the provision and use of parking space to some of the more elaborate methods of road pricing now being investigated – are applicable to traffic generally, they could be equally or more applicable to any special town cars

But however desirable personal transport is, and however efficient a more widely-based system of it can be made, decisions about the role for personal transport in towns must, it seems to us, take account of a wide range of planning, amenity and other factors Any assessment of the desirability of having a system of citycars can be made only by comparison with other possibilities In London, the majority of all person-journeys to the central area – and particularly at peak times – are at present made by public transport. In smaller cities, the proportion made by public transport is less – and sometimes very much less It is not clear to what extent cities will rely respectively on public and private transport in the long term future The trend in some cities abroad towards re-establishing public transport systems, after having done a very great deal to provide for the extensive use of cars, suggests that the right roles for public transport and the private car may still not be clearly discernible No system of personal car transport that we have been able to visualise can make as good use of road space per person as public transport. Yet the car offers a standard of service – in terms of convenience, comfort, availability, and so on – never likely to be achieved by any urban public transport system What we do not know is how much value the public will attach to the advantages a car can offer and how much the community will be prepared to pay to have the necessary facilities. Such indications as there are suggest to us that people are prepared to pay a good deal for the use of personal transport. We have tried to show how the community if it wants to make extensive use of cars, could do so with much less road and parking space than is needed by the present pattern of car use, and how it could be achieved with far less demolition and rebuilding of towns than would be needed to cope with the same numbers of cars of the present sort, and with their present pattern of mixed traffic use We think that the relative roles of public and private transport need to be decided upon in the light of this

Arriving at a decision on a possible role for citycars, alongside wide ranging decisions about the form of cities and in the light of appraisals of all the forms of transport open to the community requires studies of the relative costs and benefits – taking into account the physical resources involved and also the less tangible amenity and other considerations – of a range of possibilities. This is an exercise well outside the scope of this study, but one that would need to be attempted before any final conclusions could be reached about the place of the very small car in solving the urban traffic problem

It may at first appear that in looking at possible developments of cars, we have taken a longer time-scale than in looking at buses and goods vehicles. We would make two points. The developments we have referred to in the bus field, although not dramatic would no doubt take a good few years to come into effect. Second, the zinc-air battery, which may well become a practical proposition, may prove a useful and worthwhile power source for both small buses in city centres and for goods vehicles in towns As far as can be foreseen at present, it will always be a more expensive power source than the internal combustion engine. But if, as we suggest, there is increasing goods vehicle traffic in towns at night, the cost penalty might become worth accepting for the benefit of less noise

In this study we have not considered in any depth developments that may be possible in forty or fifty, rather than twenty or thirty years' time Two types of development may by then be complementary. Developments in electric power and in electronics may make possible vehicles driven electrically and controlled electronically, as to both spacing and destination In such a system, driving as we know it today would disappear. Secondly, there are signs, among car-using societies, that greater use of the car leads to a growing tendency to regard its use in towns solely as a convenient, and increasingly indispensable means of transport, rather than as a form of pleasure. As a result, town driving may become less personal, more disciplined and more subject to social responsibility Both engineering and psychological factors point to the ultimate development of automated individual transport in cities.

Appendices

Appendix A

Organisations with whom the Working Group have been in touch

Alden Self-Transit Systems Corporation
Alexander Geddes & Co Ltd
Austin Crompton Parkinson Electric Vehicles Ltd
Automobile Association
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Appendix B

Personal transport in towns: Short term hire and interchange arrangements

Private ownership and use are not essential to car use in towns. Many journeys into towns are journeys to work which are made in medium or large sized cars, often with the driver as the sole occupant. These cars frequently lie parked and unused throughout the day. Short-term hire and interchange systems are possible means of overcoming the waste of road and parking space resulting from this sort of use of private cars in town centres.

Short-term hire systems

Various systems of personal short-term hire, sometimes called pool ownership or club hire, have been associated with the use of specialised town vehicles.[1] The basis of such systems is a fleet of cars operating within a town area, all members of the club or organisation that operates the pool of cars having access to them for any journey in the area.

The unqualified advantages of such a system are that the best use could be made of mechanical parking, because it would not be necessary to select any particular car from a park, while municipal or company ownership would be expected to make for economies of scale in the servicing and repair of vehicles.

A substantial advantage would result if the demand for pool vehicles was such that the whole fleet was well used throughout the day, for in such circumstances fewer vehicles and less overall parking space would be needed than with a system based on private ownership. However, demand is not constant throughout the day. Many of the pool cars needed at peak hours would not be used at off-peak times, so the handling and storage of pool cars could become a big problem.

A basic difficulty with pool hire is providing vehicles where and when they are required. A system in which pool cars could be left at the kerbside would be very difficult to administer, so that parks where they could be left or hired would almost certainly have to be provided at a large number of points within the town. Alternatively, cars would have to be made available at the users' homes or places of work, which would inevitably result in substantial handling and administrative costs. Even if there were a large number of parking centres, there would be the problem of moving cars between parks, for demand would not necessarily coincide with the location of available vehicles. Some indication of the extent to which cars might have to be moved to meet demand is perhaps given by the extent to which taxis make unengaged journeys in a typical working day. On average London taxis cover 38% of their total mileage while unengaged.[2] If there was no collection and transfer of vehicles to meet demand, the quality of the service in some areas would be very poor, which would make pool hire an unattractive alternative to private ownership in these areas.

A pool system has two main design implications for the town car. First, because of the continuously varied use to which it would be put, a pool car would need to be of more rugged construction than a vehicle intended for private use. Second, it would have to be fitted with a device which would enable the user to be identified and the time or mileage for which the vehicle was used to be recorded or charged for. This would be essential if members were to be charged for journeys made on the basis of use.

However, the problems of fraud and mis-use would be formidable. If keys or discs were employed, there would be no easy way of dealing with their loss by members, for the finder would have access to all pool vehicles, while the pretended loss of a key could afford a dishonest member use which might not be easily detected. Vandalism could also be a serious problem. Although these problems are not necessarily insuperable, they might be very costly to overcome.

A serious disadvantage of pool hire as an alternative to private car ownership is that users could not leave private belongings in the car. This is an important factor for shopping and many business journeys. Even discounting the problems of operation, the convenience of pool hire could never compare with that of sole use of a vehicle.

Interchange arrangements

Interchange arrangements are often associated with a pool system of car ownership in which it is suggested that ordinary cars would be prohibited from the central area of a town and that the only cars allowed into the town centre would be some special vehicles into which drivers would change at interchange points located on the perimeter of the central area. It is generally suggested that the town centre cars would be owned on some pool basis, but it would also be possible to have an interchange system linked with the private ownership of town cars.

Interchange points would have to provide space in which both conventional and specialised town cars could be parked, and allow easy and immediate access from one type of vehicle to the other. Congestion and queueing at the interchange points would have to be avoided, for any delay and inconvenience in changing cars would off-set the saving in journey times that the specialised car was designed to achieve in the town area. The provision of interchanges could well present severe practical difficulties, which can best be illustrated by looking at the way in which such arrangements might apply to London.

Nearly 400,000 journeys are undertaken every weekday by private transport into the central London area.[3] Of these, over a third are journeys to work. Even assuming that the required parking space for conventional vehicles at the perimeter did not

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[1] For example by the Battelle Institute of Geneva, StaRRcar and Rank.

[2] See *London Traffic Survey* (1962), vol. 1, Chapter 8, L.C.C. 1964

[3] See *London Traffic Survey* (1962), vol. 1, Chapter 6, L.C.C. 1964

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exceed this figure, the parking space required would be considerable. For a small central zone with an average radius of 1½ to 2 miles, which would just cover Inner London, the length of the perimeter ring would be about 12 miles. It would be necessary to have around this perimeter the equivalent of over 100 interchange points each capable of garaging 1,000 ordinary cars. This would mean six-storey car parks, each covering about an acre, every 200 yards. In practice, these parks could be staggered to reduce the concentration at the perimeter but the difficulties created by the scale of the problem would remain.

This difficulty could be reduced by moving the interchange parks further out. If, for instance, the central zone was of about 5 miles radius, far fewer parks would be required at less frequent intervals around the perimeter. But additional problems would be created, for the majority of people living within the perimeter ring could not then easily take advantage of the perimeter interchange parks. There were 315,000 such car owners in 1962 among a total area population of 3 millions. If the advantages of town car use were not to be denied to these people, they would either have to own their town cars, or interchange parks would also have to be provided at regular intervals within the central zone. Extensive private ownership would of itself show up the inadequacy of interchange as an alternative pattern of use, for in these circumstances it would be no more than a supplement to private ownership, while the provision of parks at reasonable intervals within the perimeter zone would considerably increase the cost of interchange arrangements. If on the other hand, parks were not easily accessible, users within the central zone would be greatly inconvenienced.

Thus if the central area were limited to the commercial heart of the city, the demand for specialised town cars would lead to a concentrated ring of large car parks, creating great difficulties of cost, administration and space. On the other hand, if in London the perimeter ring were set at a radius of about five miles from the centre, the advantages of town car use would be denied to many people, unless additional arrangements were made. Either it would be essential for private ownership to continue on a large scale, or else the overall cost of providing interchange arrangements would be greatly increased by the need for parks within the perimeter area.

Although a general interchange arrangement does not seem likely to be practicable or useful for the majority of car journeys into a town centre, it might provide a useful and workable facility for travellers coming to town by car from some way out. Such a person might reach the town in a medium or large car, and then wish to take advantage by short-term hire of the facilities offered by a citycar. As few interchange parks would be required to cater for this traffic, there would be less difficulty in siting them; such an arrangement might provide a small but valuable supplement to the pattern of private ownership and door-to-door use that might apply generally to citycars.

Appendix C

The concentration and significance of pollutants found in streets

In Chapter 9, figure 9·4 shows the maximum and typical winter concentrations of pollutants found in city streets but for the purpose of considering the medical and other aspects of the problem it is convenient to deal with pollutants individually.

1. Carbon monoxide

Carbon monoxide is a poison. It is colourless and odourless and therefore insidious in its action. Measurements in London[1] have shown mean levels of carbon monoxide of over 50 parts per million (ppm) over a ten minute period, levels of over 200 ppm for short periods, and peak concentrations of 200 ppm at the Bank and 360 ppm on the pavement at Oxford Circus. Surveys in Paris,[2] Frankfurt and other European cities also show that pollution by carbon monoxide in the street is commonplace. Almost any town with a high density of traffic is likely to have this problem and where dispersion is poor, for example, in narrow streets, fairly high concentrations will sometimes occur.

The effect of inhaling carbon monoxide is to reduce the ability of the blood-stream to carry oxygen to the tissues. Its existence in the body is usually measured in terms of percentage of the blood that is saturated by it. Much work has been done to show the blood saturation under different conditions; a person doing moderate exercise in air containing 100 ppm of carbon monoxide (the present industrial maximum allowable concentration) will reach 8% saturation in one hour and a steady state at 16% in 2½ hours. Walking about in 350 ppm would produce 16% saturation in half an hour and 25% in one hour.

A lot of work has been done to determine 'safe' concentrations of carbon monoxide. In the past, this has often meant those concentrations at which the subject developed no symptoms such as headaches and giddiness. More recent medical research work has shown that lower concentrations (for example, that sufficient to lead to 5 to 10% saturation) can affect a person's ability to perform skilled tasks, such as driving a motor car. Concentrations of well over 100 ppm – which can produce 8% saturation within an hour – have been measured inside cars. The situation in stationary or slow-moving traffic is therefore potentially serious. This emphasises the need, particularly where forced ventilating systems are used, to draw in air from regions well above and as far removed as possible from the exhaust of other vehicles.

It is also possible that carbon monoxide, petrol fumes, alcohol, etc., might act together and still further impair a driver's ability. This and other possibilities are being investigated but at this stage no conclusions can be drawn. In the meantime, the effects of carbon monoxide alone and the possibility that it might be a contributory cause of some road accidents lead us to view the prospect of growth of carbon monoxide pollution with some concern.

2. Smoke

Smoke from vehicles can add appreciably to the pollution already in the atmosphere. Measurements made near traffic signals at busy intersections and also at about 40 and 100 yards from the road – where only background levels exist – show that at places close to heavy traffic levels of twice the winter background level of about 0·3 milligrams per cubic metre may occur.

Smoke takes various forms. The most common are blue smoke from burnt oil and black smoke from diesel engines. Blue smoke comes chiefly from worn engines or two-strokes in which the fuel mixture contains too much oil. No new engine design considerations are therefore involved in avoiding this form of smoke. Black smoke from diesel engines is objectionable but its effects on health and well being are difficult to determine. The smoke exists mainly as small particles of carbon but may also contain sulphur dioxide, which, in sufficient amounts, can cause bronchial irritation. Very black diesel smoke may also contain carbon monoxide and hydrocarbons in the form of benzpyrene and related compounds. Even if smell and visible smoke are not harmful to health, they are nauseating and a possible threat to road safety and we consider this to be a sufficient reason for reducing this form of pollution.

3. Hydrocarbons

Both petrol and diesel fuel consist mainly of hydrocarbons which, if burnt completely, are harmless. But some fuel gets through all types of engine unburnt and some is emitted in different form after complex reactions. Hydrocarbons include a big range of compounds but the significance of some of them outweighs the rest. The most widely publicised is 3·4 benzpyrene – but the investigations carried out by the Air Pollution Research Unit show that, except in tunnels, the amount contributed by motor vehicles is far less than the general background concentrations in large towns. Contrary to popular belief, even the black smoke from diesel engines is an insignificant source of this type of hydrocarbon. The fact that some hydrocarbons, such as 3·4 benzpyrene, can cause cancer in animals has led to the allegation that they may contribute to the increase in lung cancer. But the Air Pollution Research Unit has shown that even in diesel bus garages, and despite the presence of diesel smoke, there were barely discernible increases in the level of benzpyrene above the general background level. Furthermore, the patterns of the increases over time of lung cancer and of the use of diesel vehicles seem inconsistent with any causal relationship between them. We, therefore, think it important to make it clear that there is at present no conclusive evidence on which to blame either diesel or petrol engined vehicles for the increase in deaths from lung cancer.

[1] R. E. Waller, B. T. Commins and P. J. Lawther (1965), *Air Pollution in a City Street*

[2] H. Moureu (1964), *Carbon Monoxide as a Test for Air Pollution in Paris due to Motor-vehicle Traffic.*

Hydrocarbons from unburnt and 'cracked' fuel include those which, through photochemical reactions, produce Los Angeles-type smog. But, as explained in Chapter 9, we do not think this is likely to create a serious problem in this country.

4. Sulphur dioxide

It has been estimated that for the whole of the United Kingdom, petrol and diesel engines contribute respectively 1·4% and 4·2% of the total sulphur dioxide emitted from all sources. We do not, therefore, consider it to be an important pollutant from motor vehicles at present. But a big reduction in sulphur dioxide from other sources and a simultaneous increase in the number of vehicles could alter the balance, and the situation should therefore be reviewed occasionally.

5. Oxides of Nitrogen

The higher the temperature and pressure at which combustion takes place, the more oxides of nitrogen are produced. Nitric oxide is formed initially and this may be oxidised subsequently to form nitrogen dioxide. The maximum concentration of oxides of nitrogen found in London streets – at 0·05 to 1·5 ppm – is far below the maximum safe industrial level and they are therefore not thought to be medically significant.

In high concentrations, nitrogen dioxide is dangerous as it produces deep seated irritation of the lungs. Recent experimental work suggests that constant exposure to concentrations of 5 to 15 ppm of nitrogen dioxide can result in permanent damage to the lungs but the concentrations found in air polluted by motor vehicles (even that in the Blackwall Tunnel) are well below these sort of levels. There appears, therefore, to be no direct medical hazard from oxides of nitrogen from motor vehicles. But they can contribute to the formation of photochemical smog.

6. Lead

There are many additives to both fuels and lubricants but the most important is tetra-ethyl-lead, which is added to petrol (but not to diesel fuel) as an anti-detonant.[3] It is emitted as lead salts. The Air Pollution Research Unit found the mean annual concentration of airborne lead in Fleet Street, London, was 3·2 micrograms per cubic metre, which compares with the industrial maximum allowable concentration of 200 micrograms per cubic metre. Although lead is a serious poison, the amount emitted into the air by motor vehicles is medically insignificant. The effects of long term exposure to lead have not, however, been established beyond doubt and the position is being carefully watched.

7. Aldehydes

Some of these compounds are probably responsible for the characteristic smell of petrol and diesel exhaust fumes but not even the concentrations found in garages approach the levels which are medically significant. So far as we are aware no practical method of eliminating the odour of petrol and diesel exhaust fumes has yet been found. Any such development would probably be more a matter of fuel technology than of vehicle or engine design.

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(3) i.e. to increase the octane rating of the fuel to make it more suitable for use in high compression engines.

Appendix D

The causes of pollution from diesel and petrol engines

Much has been written about the causes of air pollution from diesel and petrol engines and what follows is intended as no more than a summary of the salient points.

1. Diesel engines

The principal cause of the emission of excessive smoke from diesel engines is over-fuelling. To provide a margin against smoke emission, new diesel engines are rated 10–25% below the power that would be achievable if all the air were consumed and there is a corresponding reduction in the amount of fuel injected. Increasing the fuel injected above the design level (with consequent production of smoke and possibly carbon monoxide) is therefore a temptation to operators.

All diesel engines are prone to emit some unburnt or partly burnt hydrocarbons when starting from cold. The amount depends on climatic conditions, engine type and size and the volume/surface ratio of the combustion chamber. But this type of smoke does not usually persist for long and is produced for only a very small proportion of running time.

Inadequate maintenance of an engine (including choked air filters, faulty speed governors and excessive bore wear) and particularly faulty fuel injection equipment is likely to result in excessive smoke. The effect may be continuous or may show as puffs of black, blue or white smoke when engine operating conditions are changed, e.g. accelerating after prolonged idling. Even a well-maintained engine may, however, have only a small margin between a clean and dirty exhaust, so that there is a risk that the engine will smoke when over-loaded or because of external factors such as changes in air temperature or pressure. The fact that changes in weather conditions are sufficient, with a finely adjusted engine, to change an exhaust from clean to smoky, illustrates the difficulty of achieving consistent standards of exhaust cleanliness.

2. Petrol engines

One of the main causes of excessive carbon monoxide from petrol engines is the use of over-rich mixtures. Mixtures up to 20% over-rich increase power output on full throttle and are often used to improve the power to weight ratio of cars.

Distribution of fuel to the cylinders is often unequal and a richer mixture may be necessary to compensate for this. Extra fuel is required when accelerating to compensate for that deposited on the walls of the inlet manifold under conditions of low manifold vacuum, which discourages evaporation. A rich mixture has been widely used when the engine is idling to compensate for dilution of the incoming charge by residual exhaust gases at small throttle openings. Very rich mixtures are needed for cold starting if the air-fuel mixture in the cylinders is to be ignitable. The carburettor is designed to meet all these operating conditions as far as possible but the difficulties are such that compromise settings are necessary, with the mixture often being considerably richer at low speeds than it need be.

The amount of unburnt and partly burnt hydrocarbons emitted by a petrol engine exhaust depends not only on the richness of the mixture but also on two other basic factors – the quantity of unburnt fuel which enters the exhaust system, and how much additional burning takes place during the exhaust process.

The quantity of unburnt fuel entering the exhaust system is influenced by engine 'over-run',[1] 'wall quenching',[1] valve overlap and ignition timing. Under over-run conditions an appreciable proportion of the fuel passes out of the cylinder unburnt; this results in the level of hydrocarbons in the exhaust being much greater during deceleration than at any other time. Wall quenching occurs under all other operating conditions and also results in hydrocarbons in the exhaust. The amount is influenced by turbulence and wall temperature but depends mainly on the surface to volume ratio of the combustion chamber. The effect is worse with small cylinders. Advanced ignition timings also result in more hydrocarbons in the exhaust except during over-run. Some of the hydrocarbons unburnt in the cylinder will be oxidised during the exhaust process but this is dependent on high temperature and the availability of excess air in the exhaust system.

Fumes from the crankcase ventilator can make a significant contribution to the total of hydrocarbons emitted by the petrol engine. They result from piston 'blow-by'[2] which is influenced by many of the variables of engine design and operation. It is aggravated by inadequate maintenance and excessive wear.

(1) Engine 'over-run' occurs when the throttle is closed at high engine speed. 'Wall-quenching' is the chilling effect on combustion of the combustion chamber walls, which results in a thin skin of air/fuel mixture remaining unburnt and passing into the exhaust.

(2) 'Blow-by' is the escape of some of the high-pressure gases from the combustion chamber, past the piston rings into the crankcase. They include the products of combustion and fuel.

Appendix E

Glossary of terms used in the report

Air suspension systems

Suspension systems which utilise flexible airbags or cushions located between the axles of the vehicle and the chassis. By automatic regulation of the air pressure within the bags, depending on the vehicle load, a constant chassis riding height can be maintained.

Coasting noise

The noise emitted by a free-running vehicle with the engine idling. It consists of e.g. tyre to road noise, wheel and suspension noise, body resonance and transmission noise.

Coefficient of road/tyre friction

The coefficient of friction, u, between the vehicle's tyres and the road surface.

Construction and Use Regulations

The Motor Vehicles (Construction and Use) Regulations 1966 made under the Road Traffic Acts 1960 and 1962.

Directional stability

The ability of a vehicle to maintain a selected course under the influence of external forces, such as strong cross-winds.

Engine Rating

The recommended maximum brake horse power to give, with proper maintenance, a satisfactory service life.

Ergonomic requirements

The design and arrangement of, e.g., the controls and the seats to suit the human being and to minimise the physical and mental effort required to control the vehicle.

G

The rate of acceleration of a free falling body = 32·2 ft per second, per second.

Grade separation

The separation of two roadways, by a fly-over or under-pass, to allow traffic on the one road to proceed without interfering with traffic on the other road.

Lateral acceleration

The sideways force exerted on a vehicle when travelling on a curved path, e.g. when swerving or cornering, usually expressed in terms of 'g'.

Proximity warning system

A warning system designed to detect and warn the driver of the presence of vehicles or obstructions on the road ahead.

Regenerative braking

A method of braking for electric motors in which the motors are operated as generators, by the momentum of the vehicle being braked, the electrical energy so generated being fed back into the supply or dissipated as heat.

Retarders

Hydraulic. A turbine device (similar in principle to a hydraulic torque converter) in which a rotor attached to the propellor shaft and a stator assembly mounted on the chassis create a torque, in reverse direction to the normal driving torque, thereby providing a braking effect on the vehicle.

Electric. A device consisting of soft steel discs mounted on the propeller shaft, and rotating between stationary electromagnets fixed to the vehicle chassis. The braking effect is obtained through eddy currents generated in the rotating discs when the electromagnets are energised by the electrical system of the vehicle.

Rolling resistance

The resistance to motion mainly due to deformation of the tyres in contact with the road surface owing to the weight of the vehicle.

Rotary combustion engines

Internal combustion engines in which the gas forces, arising from combustion in a combustion space formed between a geometrically shaped rotor and a suitably geometrically shaped casing, impart a rotary motion to the rotor.

Servo system

A system for magnifying a relatively small effort.

Star town

A form of town development to deal with growth and contain urban sprawl. Compact satellite towns are developed within easy access of the main town centre and in a peripheral ring around it.

Steering geometry

The general layout of the steering linkage and its relationship to the steerable wheels.

Thermal efficiency

The ratio of the work done by an engine to the mechanical equivalent of the heat supplied by the fuel.

Acknowledgments

Photographs

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Figures

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'Essays in Local Government Enterprise' Vol II, ed. Ellis Hillman, Merlin Press 1965 – *Figure 1:11.*
Leicester Traffic Plan 1964 – *Figure 1.3.*
'London Traffic Survey (1962)' Vol. I – *Figure 1:10.*
'Motor Car and Motor Bus' by A.F. Neal. Paper presented to Public Transport Association, May 1965 – *Figure 5.1.*
Motor Industry Research Association – *Figure 9.2.*
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'Traffic in Towns' HMSO 1963 – *Figure 1.12.*
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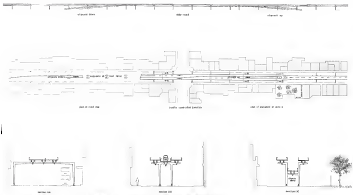

Figure [illegible] Plan, elevation and sectional drawings of overhead road structure showing ramp approaches

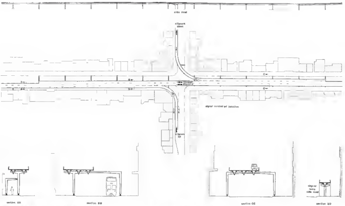

Figure 3/21 Plan, elevation and sectional drawings of overhead road structure at an intersection